Final Report

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Appendix H: Groundwater Treatability Study for PFAS Treatment for Project 1007 Bench-Scale Study Report

Project 1007 Feasibility Study
Minnesota Pollution Control Agency

MINNESOTA POLLUTION
CONTROL AGENCY

Prepared for:

Minnesota Pollution Control Agency
520 Lafayette Rd
Saint Paul, MN 55155

Prepared by:

AECOM
800 LaSalle Avenue
Minneapolis, MN 55402
(612) 376-2000
aecom.com

Minnesota Pollution Control Agency
520 Lafayette Road North | Saint Paul, MN 55155-4194 |
651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us
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Figure 163: Groundwater Sample Locations: Treatability Study and RSSCTs

Acronyms and Abbreviations

µg/L	microgram per liter
µm	micrometer
µS/cm	microsiemens per centimeter
AECOM	AECOM Technical Services, Inc.
ASTM	American Society for Testing and Materials
cm	centimeters
cm/s	centimeters per second
DI	deionized
EBCT	empty bed contact time
EC	electrical conductivity
EPA	United States Environmental Protection Agency
F400	Filtrasorb® 400
FS	Feasibility Study
ft^3	cubic feet
GAC	granular activated carbon
gal	gallons
gpm	gallons per minute
H_2O_2	hydrogen peroxide
HBV	Health-Based Value
HDPE	high-density polyethylene
HFPO-DA	hexafluoropropylene oxide-dimer acid
HI	Hazard Index
HPLC	high-performance liquid chromatography
HRI	Health Risk Index
HRL	Health Risk Limit
IX	ion exchange
kg/L	kilogram per liter
$KMnO_4$	potassium permanganate
L	liter
L/D	liters per day
L/kg	liters of water per kilogram of sorbent
MBWA	Multi-Benefit Well Array
MCL	Maximum Contaminant Level
MDH	Minnesota Department of Health
mg/L	milligrams per liter
min	minutes
mL	milliliter
mL/min	milliliters per minute
MPCA	Minnesota Pollution Control Agency

MTZ	mass transfer zone
mV	millivolts
NaOCl	sodium hypochlorite
ng/L	nanograms per liter
NTU	nephelometric turbidity unit
ODS	Oakdale Disposal Site
P816E	ChemTreat Inc. Anionic Polymer
Pace	Pace Analytical Minnesota
PEEK	polyetheretherketone
PFA	Purolite PFA 694E
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic Acid
PVC	polyvinyl chloride
rpm	revolutions per minute
RSSCT	Rapid Small-Scale Column Test
SAFF®	Surface Active Foam Fractionation
SGS	SGS AXYS Analytical Services Ltd.
SLR	surface loading rate
SSC	Site-Specific Water Quality Criteria
Std. Dev.	Standard Deviation
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
WCL	Washington County Landfill

H1 Introduction

The Project 1007 (Site) Feasibility Study (FS) evaluated potential remedial alternatives for per- and polyfluoroalkyl substances (PFAS) impacted surface water, sediment, and groundwater to protect drinking water supply in the Twin Cities East Metro as a result of historical disposal of PFAS containing waste at the Oakdale Disposal Site (ODS) and Washington County Landfill (WCL). ODS is located near the headwaters of Raleigh Creek, which carries PFAS containing surface water downgradient to the confluent with Project 1007. Project 1007 was constructed by the Valley Branch Watershed District in 1987 to provide flood mitigation for the Tri-Lakes area. It consists of a system of stormwater pipes, open channels, catch basins, and two dams that convey water from the Tri-Lakes to the St. Croix River. Historically, gradient control water from WCL that was PFAS-impacted was discharged into the Project 1007 Conveyance System.

As a result of the PFAS impacts in Raleigh Creek, Project 1007 has likely also increased the spread of PFAS containing surface water. In addition to groundwater impacts resulting from both ODS and WCL, infiltration of PFAS containing surface water to groundwater has also resulted in widespread groundwater impacts, including in the aquifers used for drinking water (Shakopee and Jordan Aquifers) in the East Metro. The project area (Site) consists of these areas that are impacted by PFAS surface water and groundwater. More details on the Project 1007 Site can be found in Section 5 (Conceptual Site Model) of the FS.

As part of this FS, remedial alternatives to address groundwater, specifically the drinking water aquifers throughout the Site are proposed and evaluated. These include evaluating where treatment should occur and potential technologies. More information on potential treatment options can be found in Section 11 (Remedial Alternative) of the FS, Appendix J (Technology Analysis for Project 1007 Non-Drinking Water Treatment Alternatives) and Appendix K (Multi-Benefit Well Array [MBWA] Technology Analysis). A Surface Active Foam Fractionation (SAFF®) pilot study was also conducted to evaluate this technology for the treatment of surface water and groundwater; more details are provided in Appendix E (SAFF® Pilot Study Report). The use of filtration media, either granular activated carbon (GAC) or ion exchange (IX) resin, were also considered for PFAS removal from groundwater. The purpose of this study is to evaluate GAC and IX usage to compare these PFAS treatment technologies to others like foam fractionation and reverse osmosis. Rapid Small-Scale Column Studies (RSSCTs) are a relatively fast and inexpensive way to evaluate the frequency that the media would require changeouts.
On behalf of the Minnesota Pollution Control Agency (MPCA), AECOM Technical Services, Inc. (AECOM) has prepared this treatability study report to present the approach, results, and conclusions from a bench-scale treatability study conducted to evaluate two adsorption-based treatment options for the removal of PFAS from four groundwater samples. Tested samples were as follows:

- Raw, untreated water collected from the Jordan Aquifer south of Eagle Point Lake which is representative of the water that would be treated as part of the MBWA and pump and treat alternatives,
- SAFF® treated water from the Shakopee Aquifer near Tablyn Park to evaluate the potential media savings by treating first with SAFF®
- Raw, untreated water collected from the Shakopee Aquifer at the same location as the SAFF® to provide a comparison to the SAFF® treated water
- Raw, untreated water collected from the Quaternary (shallow) Aquifer immediately downgradient of WCL to evaluate media usage near one of the source zones

These locations are shown in Figure 163 in Appendix A. Treatment of groundwater from ODS was not evaluated as part of this study as development of remedial alternatives for that source area will be considered as part of the superfund process at the Site, as ODS is currently managed under the MPCA Superfund Program. As part of this investigation, the efficacy of various pretreatment approaches was also evaluated for the removal of other contaminants that would negatively impact the sorbent's optimum performance.

This treatability study report includes the treatability study goals, a summary of the technical approaches and methodologies used, the results from the pretreatment and treatability tests, and a conclusion section summarizing the overall findings of the treatability study.

H1.1 Treatability Objectives

The overarching objective of this treatability study was to evaluate the removal of PFAS on four water samples using GAC and an ion exchange (IX) resin. Specifically, two untreated drinking water aquifer samples (from the Jordan and Shakopee Aquifers), one water sample from shallow groundwater near WCL, and one Shakopee Aquifer sample treated with SAFF® were tested. Pretreatment strategies were also evaluated to improve sorbent performance. The specific objectives of the bench-scale treatability study included the following:

- Determine if influent iron and manganese are acceptable for the PFAS adsorption process in the Jordan Aquifer groundwater.
- If not acceptable, determine the best pretreatment process through bench-scale treatability testing to control the concentrations and/or levels to be acceptable for the adsorption process in the Jordan Aquifer groundwater.
- Evaluate two adsorbent media for regulated PFAS compounds in each impacted test water via Rapid Small-Scale Column Tests (RSSCTs) for the following media:
    - Calgon's Filtrasorb® 400 (F400), a bituminous coal-based GAC; and
    - Purolite's PFA 694E (PFA), a single use, divinylbenzene-crosslinked polystyrene IX resin
- Evaluate the relative performance among the adsorbent media while tested under controlled laboratory flow-through conditions.
    - Evaluate the time to breakthrough of PFAS compounds in the media tested; and
    - Evaluate the volume of water treated per mass of sorbent (specific throughput rate).
- Determine the optimum media for PFAS removal from each test water.

The conclusions of the study, along with proper scaling parameters, can aid in informing the selection of the treatment system. Results from RSSCTs are also used in Appendix J (Pump & Treat) and Appendix K (MBWA) to estimate yearly media usage and associated costs.

H1.2 Test Approach

The main tasks of this bench-scale evaluation included:

- Baseline characterization of water quality parameters in four as-received waters;
- Pretreatment of Jordan Aquifer groundwater to remove iron and manganese; and
- Treatability of PFAS by GAC and IX resin under flow-through conditions via RSSCTs for each test water.

The tasks described above were conducted in a sequential manner.

H1.3 Analytical Methods

Total organic carbon (TOC), alkalinity, hardness, metals, and anions were analyzed by Pace Analytical Minnesota (Pace), a third party, commercial analytical laboratory. PFAS samples were analyzed by SGS AXYS Analytical Services Ltd. (SGS). AECOM conducted measurements of pH, oxidation reduction potential (ORP), electrical conductivity (EC), turbidity as nephelometric turbidity unit (NTU), total dissolved solids (TDS), and total suspended solids (TSS) using the Austin CleanTech Hub Laboratory in-house capabilities. Details of analytical methods are summarized in Table H.1.

Table H.1: Analytical Methods Completed for the Treatability Study.

Analyte	Method	Performed by
PFAS	EPA Method 1633	SGS AXYS
TOC	9060A	Pace
Alkalinity	2320B	Pace
Hardness	2340B	Pace
Total and Dissolved Metals (iron, manganese, calcium, magnesium)	6020B	Pace
Anions (chloride, nitrate, sulfate)	9056A	Pace
pH	Hach® Benchtop Meter HQ 430d	AECOM
ORP	Hach® Benchtop Meter HQ 430d	AECOM
EC	Hach® Benchtop Meter HQ 430d	AECOM
Turbidity	Hach® Ratio Turbidimeter 18900	AECOM
TSS	2540C	AECOM
TDS	2540D	AECOM
Iron by Hach® Kit	Hach® Method 8008	AECOM
Manganese by Hach® Kit	Hach® Method 8149	AECOM

H2 Sample Collection and Baseline Characterization

Jordan Aquifer water was collected on September 17, 2024, in two 30-gallon (gal) high-density polyethylene (HDPE) drums and placed into 55-gal HDPE drums with Styrofoam peanut packing material. The drums were shipped via ground and received by AECOM CleanTech Hub Laboratory, which is part of the AECOM CleanTech Hub group in Austin, Texas, on September 19, 2024. After receipt, the sample containers were inspected for leaks and no issues were identified. The sample containers were entered into the Laboratory's logbook and initial water quality samples were collected and measured in the AECOM CleanTech Hub Laboratory. All handling of the water samples used PFAS-free materials and equipment according to AECOM's sampling guidelines based on guidance from the Michigan Department of Environment, Great Lakes, and Energy (formerly the Michigan Department of Environmental Quality) (EGLE, 2018).

The remaining three test waters were collected on October 7, 2024, in three, 5-gal containers for each location and shipped in coolers on ice. The coolers were shipped via ground and received by AECOM CleanTech Hub Laboratory in Austin, Texas on October 9, 2024. After receipt, the sample containers were inspected for leaks and no issues were identified. The sample containers from each location were combined into 15-gal HDPE drums and entered in the Laboratory's logbook. No initial water quality samples were collected at the time of inspection but were later measured in the AECOM CleanTech Hub Lab as described below. All handling of the water samples used PFAS-free materials and equipment according to AECOM's sampling guidelines based on guidance from the Michigan Department of Environment, Great Lakes, and Energy (EGLE, 2018).

Jordan Aquifer test water arrived first, and initial characterization was completed shortly after receipt. The other waters arrived later, and no initial characterization was conducted. Instead, constituents were analyzed after the study was completed on March 28, 2025. Jordan Aquifer test water was reanalyzed on the same date as the other three test waters as a comparison of how the water quality changed over time. TSS, and therefore turbidity, decreased as the solids settled over time. In addition, the iron and manganese were also significantly lower; this was expected as the oxidation of iron and manganese is known to occur over time. Even though three of the four waters were not characterized in their raw form before the RSSCTs, these waters were characterized as filtered influent waters during the RSSCTs, which constitutes the true baseline reference sample to interpret the RSSCT results. Table H.2 summarizes results for the water quality characterization conducted on the individual drums.

The initial characterization results for Jordan Aquifer indicated an elevated iron concentration for the total measurements. The iron results obtained on the water upon arrival varied from those collected and analyzed at the time of collection. The total iron concentration from the test water preserved in the field was 3.5 milligrams per liter (mg/L), which indicated iron oxidation and precipitation occurred during transit. manganese concentrations on the other hand were much lower, at around 0.04 mg/L.

Table H.2: Initial Baseline Water Quality Results from the Four Test Waters.

Analyte	Unit	Jordan Aquifer	Jordan Aquifer (Re-Test)	Shakopee Aquifer	SAFF® Treated Shakopee Aquifer	WCL
Date of Analysis	-	10/4/2024	3/28/2025	3/28/2025	3/28/2025	3/28/2025
TSS	mg/L	3.58	< 0.057	< 0.057	2.44	2.03
TDS	mg/L	-	195.0	492.2	471.5	502.7
Iron, Total	mg/L	0.57	0.00	0.00	0.00	0.24
Manganese, Total	mg/L	0.053	0.002	0.011	0.005	0.008
Iron, Dissolved	mg/L	0.00	0.00	0.00	0.00	0.02
Manganese, Dissolved	mg/L	0.032	0.001	0.005	0.005	0.006
pH	-	8.00	7.80	7.81	7.96	7.85
ORP	mV	292.5	491.4	478.2	459.6	462.1
EC	µS/cm	366.5	333.8	713.0	731.2	798.1
Turbidity	NTU	7.4	0.48	0.45	0.34	4.80

Legend: µS/cm = micro-Siemens/cm; mg/L = milligrams per liter; mV = millivolts.

Historical data from three of the water sources (Jordan Aquifer, Shakopee Aquifer, and SAFF® treated Shakopee Aquifer) can be found in Table H.3 and indicate that TSS and iron can be more variable and higher than the water received for this study. Thus, the variability and higher levels of TSS and iron should be considered for field implementation of the pretreatment approaches evaluated in this study, especially for Jordan Aquifer water.

Table H.3: Historical Water Quality Results from the Three Test Waters.

Analyte	Unit	Jordan Aquifer		Shakopee		SAFF® Treated Shakopee Aquifer	
		Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
TOC	mg/L	1.8	0.4	1.0	0.0	2.6	2.8
TSS	mg/L	124.0	135.8	31.3	42.6	6.3	3.3
TDS	mg/L	212.6	54.6	446.3	25.5	-	-
Alkalinity, Total as $CaCO_3$	mg/L	192.0	16.5	213.0	5.4	191.2	32.8
Hardness (Calcium & Magnesium)	mg/L	217.0	1.4	301.0	15.1	200.9	98.3
Chloride	mg/L	14.7	1.8	123.3	4.6	98.5	83.7
Nitrate as Nitrogen	mg/L	1.8	0.0	3.0	0.0	1.6	1.4
Sulfate	mg/L	12.1	1.3	15.3	0.5	11.1	5.0
Calcium	mg/L	68.0	20.1	83.5	-	-	-
Iron	mg/L	113.6	215.0	1.5	2.9	0.1	0.0
Magnesium	mg/L	26.2	7.7	27.7	-	-	-
Manganese	mg/L	0.024	0.002	-	-	-	-
pH	-	8.0	0.1	7.7	0.4	8.1	0.3
Turbidity	NTU	376	670	32	-	-	-

Legend: Std. Dev. = standard deviation; $CaCO_3$ = calcium carbonate.

H3 Pretreatment Evaluation

Before conducting the evaluation of PFAS adsorption via RSSCTs, it is generally recommended that any test water should meet the water quality criteria for the adsorbent media's optimum performance. IX resin manufacturers state that when iron and/or manganese concentrations are above 0.1 mg/L, pretreatment measures need to be considered to avoid system fouling, which can prematurely shorten media life. Based upon field experience utilizing IX resin in PFAS remedial systems, iron and manganese concentrations as low as 0.1 mg/L can induce biological and mineral fouling (causing differential pressure increase) over time. In addition, TSS is recommended to be below 1.0 mg/L to prevent column plugging (ECT2, 2022).

Jordan Aquifer test water historically has manganese concentrations below the IX manufacturers recommended level; however, the total iron concentration from a field preserved sample was 3.5 mg/L. Moreover, the TSS for Jordan Aquifer was 3.6 mg/L, which was also above the IX manufacturer's water quality criteria. Due to the high iron and TSS concentrations, the test water underwent pretreatment with a focus on the removal of these two constituents.

To reduce the total iron concentrations, the use of sodium hypochlorite (NaOCl), NaOCl with catalytic media, hydrogen peroxide (H_2O_2), and potassium permanganate ($KMnO_4$) were tested. TSS removal was conducted for the same oxidation tests with the addition of NaOCl with an anionic polymer. TOC was tracked during the testing, but no specific treatment was assigned since historical TOC data indicated the TOC concentration is within a range that will not interfere with the sorbent media. The experimental design for the metal and TSS pretreatment is described in the below sections.

H3.1 Iron Removal Approach

The concentration of manganese was below the water criteria limit of 0.1 mg/L, so the focus of the metal removal evaluation was on iron. Because a significant loss of iron was observed during the storage of the groundwater, ferrous chloride tetrahydrate was spiked into the groundwater to match 3.5 mg/L as the initial iron concentration before the removal evaluation began. A manganese spike was not included since the baseline results were below the water quality limit.

H3.1.1 Sodium Hypochlorite Oxidation with and without Catalytic Media Filtration and with Polymer Addition

The addition of NaOCl to oxidize and convert dissolved iron to a solid form of iron, which could be easily removed from the water, was tested. The dosing ratio was calculated based on the stoichiometric amount of oxidant required to oxidize the dissolved iron in the test groundwater. A NaOCl dose assuming 100% oxidation was first tested followed by a 50% dose oxidation test. With an initial iron concentration of 3.5 mg/L, the oxidant concentrations used for NaOCl as free chlorine were 4.65 mg/L and 2.33 mg/L, respectively.

To improve the overall oxidation and removal of Fe, two catalytic media were tested in conjunction with NaOCl: GreensandPlus™, a product sold by Inversand Company and pyrolusite as OxiPlus75™, sold by WaterSurplus. In addition to the NaOCl with and without catalytic media tests, an anionic polymer, specifically P816E supplied by ChemTreat Inc. was added at 10 mg/L in conjunction with NaOCl at 50% dose to enhance settling. The outcome of the combined removal process focused on the removal of iron from the water, but also reduction in TSS and TOC to determine the overall effectiveness and ability to remove multiple constituents. Table H.4 presents the summary of the NaOCl test regime.

Table H.4: Sodium Hypochlorite Testing Regime and Sample Count.

Treatment	NaOCl, Oxidation (%)	Iron, Total	Iron, Dissolved	Free Chlorine	TOC	TSS
NaOCl	50	5	8	2	4	5
NaOCl	100	1	2	2	-	1
NaOCl + 10 mg/L P816E	50	1	4	3	-	1
NaOCl + GreensandPlus™	Various	13	6	5	6	6
NaOCl + Pyrolusite	Various	13	6	5	6	6

The NaOCl oxidation tests were conducted using a jar tester. 1 liter (L) of the groundwater was transferred to a mixing vessel, and iron was spiked, targeting 3.5 mg/L as total iron. Then, the NaOCl was added, and the free chlorine and dissolved iron concentrations were measured. The solution was continuously stirred for 10 minutes, then allowed to settle for 30 minutes. After the settling period, the supernatant was analyzed for residual free chlorine and dissolved iron concentrations. The solution was quickly re-suspended, and the TSS sample was collected. A duplicate test at 50% dose oxidation with 2 L of the groundwater was performed, and the samples were collected for analysis by Pace.

The catalytic media column with NaOCl tests were conducted in a continuous flow through configuration. The column preparation underwent a pre-conditioning phase to clean and activate the media. The columns used were 36 inches long, 1-inch in diameter, clear polyvinyl chloride (PVC) tubes. The columns were packed with the layers of water washed, American Society for Testing and Materials (ASTM) 20/30 sand and the chosen catalytic media, which was activated using a dilute NaOCl solution, then rinsed with deionized (DI) water. After the media activation was finished, a layer of water washed anthracite was added to the column and the column rinsed with the DI water before the test. The list below outlines the steps performed to activate the media prior to the test groundwater introduction. Figure H.1 shows the flow directions and various layers within the columns:

1. Place small amount of Pyrex wool at bottom of column,
2. Add 2 inches of DI water cleaned gravel on top of the wool to support the media,
3. Add 2 inches of DI water cleaned ASTM 20/30 sand on top of the gravel,
4. Add 7.5 inches of each catalytic media,
5. Backwash column with DI water for 10 minutes with a 50% bed expansion to remove fines,
6. Settle and rinse column with downflow for 3 minutes at target flowrate,
7. Repeat step 5 and 6 until fines are no longer visible,
8. Soak the media in vendor recommended NaOCl solution overnight,
9. Drain and rinse with DI water in downflow until free chlorine concentration is < 0.2 mg/L,
10. Add 7.5 inches of DI washed anthracite on top of the media, and
11. Rinse with DI water in downflow direction to ensure everything is settled.

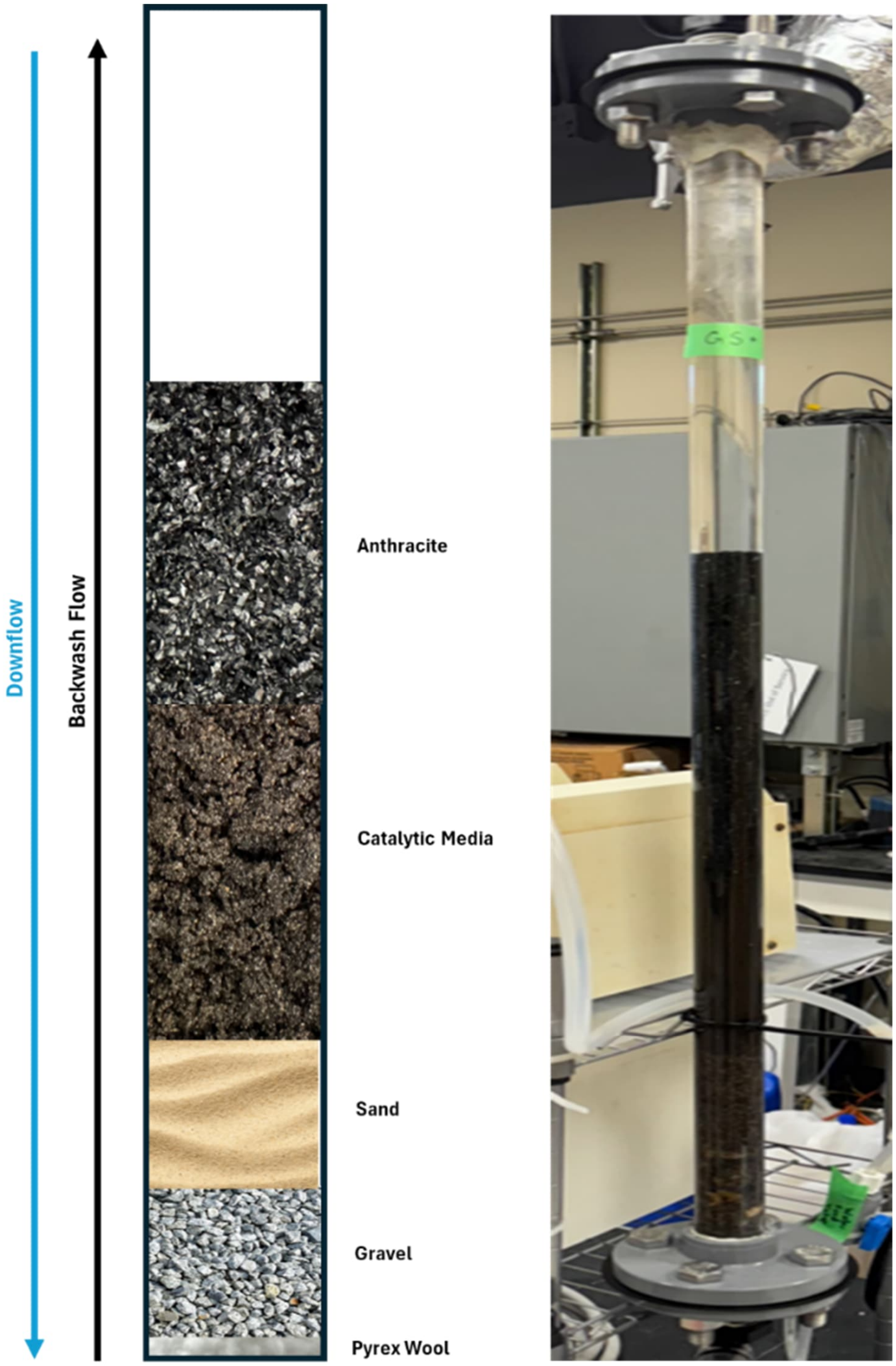

Figure H.1: Schematic and Picture of Catalytic Media Column with Directional Flows.

After a backwash procedure, the sand and media became intertwined as expected. The final DI water rinse after anthracite addition was performed until less than 0.01 mg/L of total iron was detected at the effluent. The total and dissolved iron concentrations were analyzed using Hach® Method 8008. Dissolved iron concentrations were obtained from the filtrate through a 0.45 micrometer (µm) pore size syringe filter.

During the column operation, test groundwater and the NaOCl solution at various oxidation doses were mixed via an inline static mixer installed prior to the inlet of the column. The test groundwater was fed at 41 milliliters per minute (mL/min), while the NaOCl solution (162 mg/L as free chlorine) was dosed at 1.0 mL/min. The mixed solution was allowed to travel for approximately 15 seconds before reaching the top of the column. The test was conducted for 16 hours while collecting samples every four hours (4, 8, 12, and 16 hours) for analysis by Pace and TSS by AECOM CleanTech Hub Lab. Intermittently, samples were collected for total iron and free chlorine to monitor the concentrations in the effluent. Adjustments were made to the system by increasing or decreasing the flowrate of the NaOCl solution to obtain an iron concentration less than 0.1 mg/L while keeping the free chlorine concentration less than 1.0 mg/L.

H3.1.2 Hydrogen Peroxide Oxidation Test

Another approach to convert dissolved iron to the solid phase and to oxidize TOC (though not the focus of this test) includes the use of H_2O_2. The equivalent stochiometric amount of H_2O_2 required to remove 3.5 mg/L of iron is 1.12 mg/L, which is defined as 100% oxidation, while 50% oxidation will require 0.56 mg/L. Table H.5 depicts the two conditions and samples collected during the tests. All samples collected during this testing regime were analyzed by the AECOM CleanTech Hub Laboratory.

Table H.5: Hydrogen Peroxide Testing Regime and Sample Count.

Treatment	H_2O_2, Oxidation (%)	Iron, Total	Iron, Dissolved	TOC	H_2O_2	TSS
H_2O_2	50	5	6	4	3	4
H_2O_2	100	1	2	-	2	1

The H_2O_2 tests were conducted using a jar tester similar to the NaOCl tests. One L of groundwater was transferred to a mixing vessel, iron was spiked to 3.5 mg/L, the pH was adjusted if necessary, and total iron was analyzed. Next, H_2O_2 was added, and the solution was analyzed for H_2O_2 and dissolved iron concentrations. The solution was continuously stirred for the designated reaction time and then allowed to settle for 30 minutes. After the settling period, the supernatant was analyzed for H_2O_2 and dissolved iron concentrations. The solution was quickly re-mixed and TSS sample collected. The 100% dose was run in duplicate for both iron and TSS removal, and samples were sent to Pace and TSS by AECOM CleanTech Hub Lab.

H3.1.3 Potassium Permanganate Oxidation

The addition of $KMnO_4$ to oxidize and precipitate iron was also tested. For $KMnO_4$ to be effective at removing dissolved Fe, the pH needs to be 7.5. The $KMnO_4$ was added at two dose levels corresponding to the stoichiometric amount required to provide 50% and 100% oxidation compared to the dissolved iron concentration of 3.5 mg/L. The $KMnO_4$ dose concentrations as manganese were 1.73 mg/L and 3.45 mg/L, respectively. Table H.6 presents the $KMnO_4$ test regime.

Table H.6: Potassium Permanganate Testing Regime and Sample Count.

Treatment	$KMnO_4$ Oxidation (%)	Iron, Total	Iron, Dissolved	TOC	TSS
$KMnO_4$	50	4	5	4	5
$KMnO_4$	100	-	1	-	1

The $KMnO_4$ tests were performed using a jar tester as was done for the other oxidants. One difference was that the pH was adjusted and monitored to 7.5 or higher during these $KMnO_4$ tests. Based on the AECOM CleanTech Hub Lab dissolved iron analysis results, a duplicate test was performed with the 50% oxidation dose for iron and TSS removal, and the samples were sent to Pace for confirmation of the results.

H3.2 Iron Removal Results

All iron pretreatment test results were first screened using Hach® methods in the AECOM CleanTech Hub Lab to determine the best conditions for a limited set of process evaluation. Limited test samples were sent to a certified laboratory, Pace, for confirmation analysis. The same tests underwent TSS removal steps and were analyzed by the AECOM CleanTech Hub Lab. While total and dissolved manganese and TOC were analyzed by Pace as well, all results were less than or close to the water quality criteria concentrations; therefore, they are not part of this discussion.

H3.2.1 Sodium Hypochlorite Oxidation without and with Catalytic Media

Select NaOCl oxidation tests resulted in total iron below the 0.1 mg/L criteria (Figure H.2). Furthermore, all NaOCl coupled with the catalytic media column tests had total iron concentrations below the criteria target (

Table H.7).

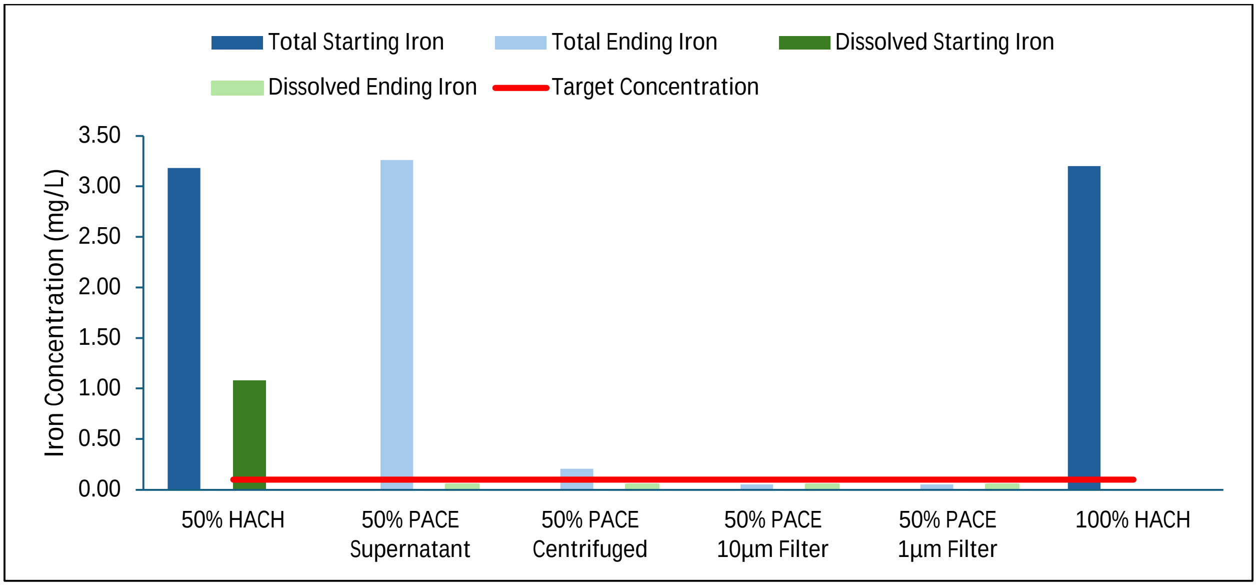

Figure H.2: Sodium Hypochlorite Oxidation for Total and Dissolved Iron Concentrations.

Table H.7: Sodium Hypochlorite with Catalytic Media Column Tests Results for Total and Dissolved Iron Concentrations.

Column	Time (hr)	Total Iron via HACH (mg/L)	Total Iron via PACE (mg/L)	Dissolved Iron via PACE (mg/L)	NaOCl Oxidant Requirement
Greensand+	4	0.00	<0.05	<0.05	73%
	8	0.00	<0.05	<0.05	58%
	12	0.00	<0.05	<0.05	51%
	16	0.02	<0.05	<0.05	44%
Pyrolusite	4	0.00	<0.05	<0.05	73%
	8	0.00	<0.05	<0.05	58%
	12	0.02	<0.05	<0.05	51%
	16	0.02	<0.05	<0.05	44%

NaOCl oxidation by itself was not enough to remove the total iron, but an additional filtration step at both 1 and 10 µm was effective. In addition, both catalytic media columns were particularly effective at removing total iron in the test groundwater, with reductions leading to greater than 98% removal. Free chlorine concentrations were monitored during the column tests by adjusting the NaOCl solution feed rate to keep the free chlorine concentration at or below 1.0 mg/L. The test started at a 73% stoichiometric oxidant dose of NaOCl to iron. Intermittent analysis of free Cl was conducted to determine if the NaOCl dose could be lowered. The final NaOCl dose was 44%, which was limited by the lowest pump flowrate; otherwise, lower doses would have been tested. Free chlorine concentrations at the end of the test were at 1.02 mg/L and 1.55 mg/L for Pyrolusite and GreensandPlus™, respectively.

Since both TOC and TSS were potential analytes of concern, they were both measured after each of these tests. TOC concentrations ranged from 2.4 mg/L to 4.2 mg/L for the NaOCl tests but were below the detection limit (< 1.0 mg/L) for the catalytic media column tests. TSS results are discussed more in Section H3.3.

H3.2.2 Peroxide Oxidation

All but one of the H_2O_2 oxidation tests were unsuccessful at reaching the target total iron concentration. Figure H.3 shows the Hach® kit and Pace results of the H_2O_2 tests on total and dissolved iron concentrations.

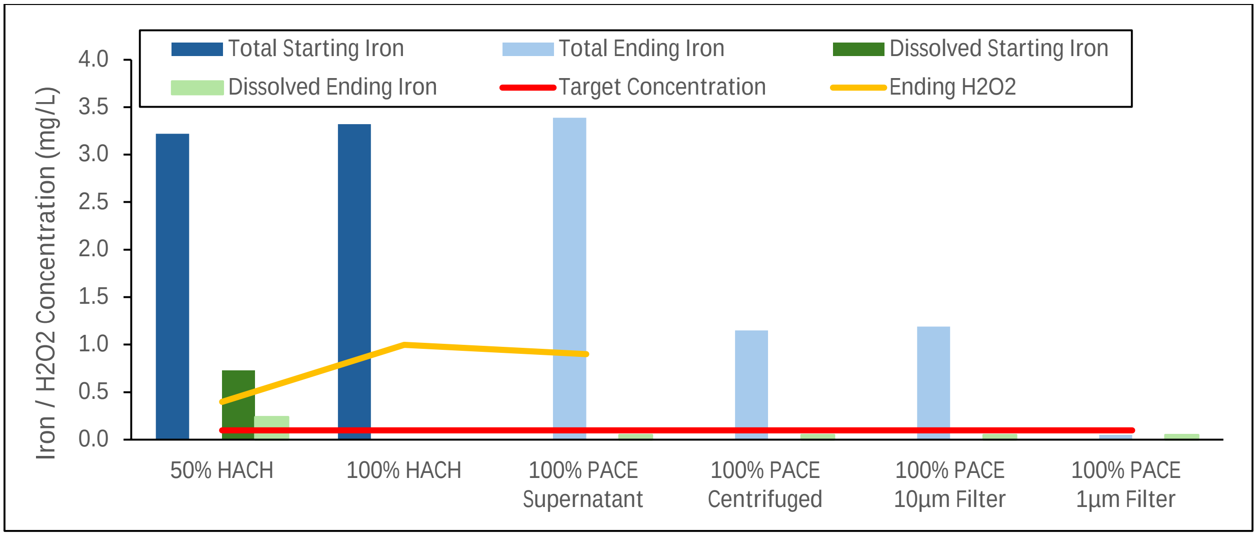

Figure H.3: Hydrogen Peroxide Oxidation Test Results for Total and Dissolved Iron Concentrations.

The H_2O_2 had minimal impact on reducing the total iron concentration to the target of 0.1 mg/L. The only H_2O_2 oxidation condition able to meet the water quality criteria for total iron was the combination of 100% dose followed by 1 µm filtration. In addition, residual H_2O_2 concentration levels were high, which could lead to column clogging and reduce resin efficiency following PFAS adsorption process. Even though the H_2O_2 oxidation tests were largely unsuccessful, TOC samples were collected and analyzed, resulting in concentrations less than 1.5 mg/L. TSS samples were collected, and results are discussed in Section H3.3.

H3.2.3 Potassium Permanganate Oxidation

None of the $KMnO_4$ oxidation tests were able to achieve the 0.1 mg/L limit for total iron (Figure H.4). Furthermore, the total manganese concentration increased due to overoxidation (Figure H.5).

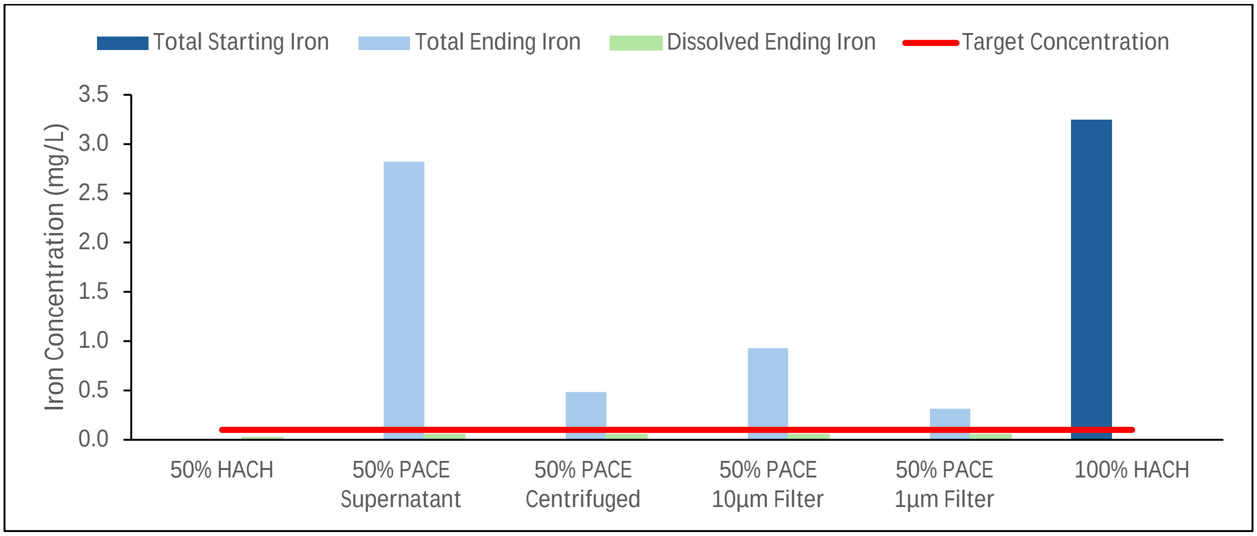

Figure H.4: Potassium Permanganate Oxidation Test Results for Total and Dissolved Iron Concentrations.

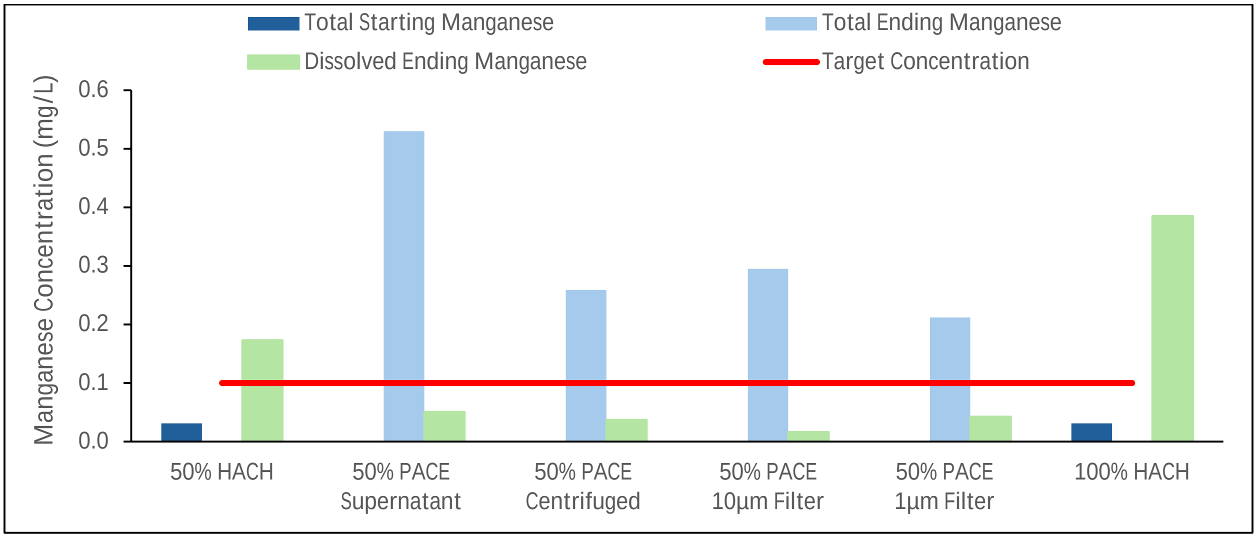

Figure H.5: Potassium Permanganate Oxidation Test Results for Total and Dissolved Manganese Concentrations.

The 50% oxidation dose of $KMnO_4$ led to a > 98% reduction in iron concentrations (dissolved) from the Hach® kit result and were verified by Pace. While the dissolved iron concentration was low, the total iron concentration was still above the target. Thus, a TSS removal strategy was coupled with the 50%

dose condition to determine if the removal of TSS would reduce the total iron concentration levels. The total iron from the Pace analysis at the end of the reaction time was above the threshold ranging from 0.32 mg/L to 0.93 mg/L. The TSS removal samples were also analyzed for dissolved and total manganese. Similar to the iron, the dissolved manganese was below the water quality criteria ranging from 0.017 mg/L to 0.043 mg/L, while the total manganese was all above the 0.1 mg/L limit, averaging 0.25 mg/L.

The 50% and 100% KMnO4 doses showed over-oxidation of manganese in the test groundwater with the end of test dissolved manganese concentration being higher than the starting total manganese concentration. The 50% dose started at 0.031 mg/L as total manganese and at the end of the test resulted in 0.173 mg/L dissolved manganese. Likewise, the 100% dose had the same starting total manganese concentration and ended with dissolved manganese being twice as high as the 50% dose at 0.385 mg/L.

H3.3 TSS During and After Iron Removal Tests

H3.3.1 TSS Removal Approach

TSS above 1.0 mg/L has been shown to hinder the flow through a fixed bed column and shorten the lifespan of PFAS targeted media (ECT2, 2022). To mitigate the potential for column plugging during the PFAS sorbent evaluation, a series of tests for TSS removal, including the previously utilized P816E anionic polymer, centrifugation, and filtration were investigated. No settling tests were conducted on the initial raw groundwater as the TSS concentrations observed during this study were too low, on the order of 2.5 mg/L to 4.5 mg/L. The TSS removal tests were conducted after the iron removal process since solid formation was expected after oxidation of the metals.

All oxidation tests previously described included TSS analysis as a standard practice. In addition, post-treatment samples from selected oxidation tests (NaOCl, H_2O_2, and $KMnO_4$) underwent several TSS removal processes. The first TSS removal approach was centrifugation, which was conducted at 2,000 revolutions per minute (rpm) on approximately 400 grams for 10 minutes. The oxidized water was split among eight 50 milliliter (mL) centrifuge tubes to obtain the required volume for TSS analysis of the supernatant, which was collected from each centrifuge tube by decanting into a collection bottle while leaving the bottom 5 mL of material containing the solids. The second and third TSS removal approaches were filtration through 1.0 µm and 10.0 µm pore size filters. The TSS residual waters (supernatant for centrifugation or filtrate from filtration) were sent to Pace for total and dissolved iron and manganese and TOC concentrations.

H3.3.2 TSS Removal Results

TSS removal results are summarized in

Table H.8. Most TSS results are above the 1.0 mg/L target threshold.

Table H.8: TSS Results After the Iron Removal Tests.

Treatment	Oxidation (%)	Sample Condition	TSS (mg/L)
Baseline Average	N/A	As Received	3.58 ± 1.41
H_2O_2	50	N/A	6.92
H_2O_2	100	N/A	8.04
H_2O_2	100	Centrifuged	2.84
H_2O_2	100	10µm Filtered	9.04
H_2O_2	100	1µm Filtered	0.19
$KMnO_4$	50	N/A	9.58
$KMnO_4$	50	Supernatant	7.16
$KMnO_4$	50	Centrifuged	< 0.057
$KMnO_4$	50	10µm Filtered	1.14
$KMnO_4$	50	1µm Filtered	4.15
$KMnO_4$	100	N/A	12.6
NaOCl	100	N/A	8.87
NaOCl	50	N/A	8.24
NaOCl	50	Supernatant	< 0.057
NaOCl	50	Centrifuged	< 0.057
NaOCl	50	10µm Filtered	14.1
NaOCl	50	1µm Filtered	0.11
NaOCl + P816E	50	10 mg/L dose	3.05
NaOCl + GreensandPlus™	73	4 hours	0.66
NaOCl + GreensandPlus™	58	8 hours	< 0.057
NaOCl + GreensandPlus™	51	12 hours	< 0.057
NaOCl + GreensandPlus™	44	16 hours	0.44
NaOCl + GreensandPlus™	-	Backwash	130
NaOCl + GreensandPlus™	-	Backwash Rinse	0.49
NaOCl + Pyrolusite	73	4 hours	< 0.057
NaOCl + Pyrolusite	58	8 hours	< 0.057
NaOCl + Pyrolusite	51	12 hours	< 0.057
NaOCl + Pyrolusite	44	16 hours	0.88
NaOCl + Pyrolusite	-	Backwash	128
NaOCl + Pyrolusite	-	Backwash Rinse	0.94

The only H_2O_2 oxidation test where the TSS achieved the specified criteria after a 20-minutes settling was after the 1 µm filtration, with a measured TSS of 0.19 mg/L. All other TSS results for H_2O_2 oxidation tests were above the 1.0 mg/L target, ranging from 2.84 mg/L to 9.04 mg/L. Thus, the 1 µm filtration, H_2O_2 oxidation method is the only viable pretreatment option for both TSS and total iron removal.

One $KMnO_4$ oxidation test yielded a TSS concentration below the target of 1.0 mg/L: 50% $KMnO_4$ dose followed by centrifugation, with a measured TSS below the laboratory detection limit. Besides the stated successful TSS removal approach, all other $KMnO_4$ conditions resulted in high TSS concentrations ranging from 1.14 mg/L to 12.59 mg/L. However, since the $KMnO_4$ tests did not lead to ideal total iron or manganese concentrations, $KMnO_4$ oxidation is not recommended as a pretreatment approach.

NaOCl oxidation with and without the catalytic media column had the lowest TSS concentrations compared to the other oxidation techniques. All the catalytic media effluents and the 50% NaOCl dose followed by centrifugation and 1 µm filtration led to TSS concentrations below the water quality criteria, ranging from <0.057 – 0.66 mg/L. The NaOCl oxidation followed by anionic polymer, P816E, lowered the TSS to 3.05 mg/L but was still above the treatment threshold of 1 mg/L. The catalytic media backwash, which was completed to mimic the maintenance after a pressure build up in the column, was expected to have an increased TSS concentration as the oxidized iron needed to be flushed off the columns. Results confirmed that the backwash was removing the iron from the media due to the high levels of iron seen in backwash samples.

H3.4 Overall Pretreatment Recommendations

The performance level of each treatment process was graded on the effectiveness at meeting the water quality criteria for iron and TSS. The excellent, limited, and poor ratings indicated the treatment process successfully met the water quality criteria; some of the criteria were met, or little to no criteria were met, respectively. TOC, pH adjustment, manganese, and free chlorine were not part of the performance level rating since these constituents were close to or below the water quality criteria in the raw test water.

Catalytic media, in conjunction with an oxidant, is an established common process for iron removal, and when combined with NaOCl, both Pyrolusite and GreensandPlus™ were graded excellent at the reduction of total iron and TSS. NaOCl alone and NaOCl with anionic polymer had a performance level of limited as either the iron or TSS under some conditions were close or less than limit of 1.0 mg/L. Finally, H_2O_2 and $KMnO_4$ oxidation received a poor rating, as the H_2O_2 only met the criteria under one specific condition, and for $KMnO_4$, neither TSS nor total iron were removed to the water quality criteria levels.

Of all the pretreatment testing, the NaOCl oxidation with catalytic media proved the best option and is recommended for both iron and TSS removal. Table H.9 summarizes the performance level (poor, limited, or excellent) for each treatment approach on the test water.

Table H.9: Pretreatment Process Performance Level.

Treatment Process	Test Water Performance Level
NaOCl	Limited
NaOCl + Pyrolusite	Excellent
NaOCl + GreensandPlus™	Excellent
NaOCl + P816E	Limited
H_2O_2	Poor
$KMnO_4$	Poor

H4 PFAS Treatability Evaluation

H4.1 RSSCT Approach

Four groundwater sources were evaluated for PFAS removal using RSSCTs: Jordan Aquifer, Shakopee Aquifer, WCL, and SAFF®-treated Shakopee Aquifer water. Two commercially available sorbents were evaluated to determine PFAS removal via adsorption in each source of groundwater. These sorbents were Calgon Carbon's Filtrasorb® 400 (F400), a commonly used GAC, and PFA IX resin.

GAC has been established as an effective sorbent for adsorption of organic contaminants, including PFAS (Labisch et al., 2018; McCleaf et al., 2017; Xiao et al., 2017). GAC can remove PFAS via adsorption due to the hydrophobic moieties in the molecular structures of PFAS compounds. Calgon's F400 is a bituminous, coal-based granular active carbon (CalgonCarbon, 2019) that has shown a relatively high adsorption capacity for PFAS compared to other GACs based on AECOM's past treatability studies. From these past treatability studies, F400 has become the benchmark, producing the highest performance in terms of PFAS removal among GACs.

The IX resin selected for this treatability study, PFA, is a single-use resin. IX resins are known for their relatively high adsorption capacity and selectivity towards PFAS (Woodard et al., 2017; Zeng et al., 202). The high removal capacity is explained by dual adsorption mechanisms. In addition to hydrophobic adsorption onto the resin, PFAS compounds are also removed via ion exchange as the negatively charged sulfonate or carboxylic groups in PFAS compounds are exchanged with a chloride ion and other replaceable ions to take a place as the functional groups of the resin matrix. IX resins have been tested for PFAS removal in bench-scale, pilot-scale, and full-scale demonstrations (Liang et al., 2022; Woodard et al., 2017; Zhang et al., 2019).

Evaluating the performance of these sorbents under laboratory-scale flow-through conditions that simulate large-scale implementation gives valuable information needed for sorbent selection and remedy design without the cost or time requirements of a pilot- or full-scale demonstration. The RSSCT experiment design is summarized in Table H.10.

Table H.10: RSSCT Experimental Design.

Column Test	Sorbent Product	Water Source	Sorbent Type	Number of Effluent Samples
1	F400	Jordan Aquifer	Bituminous GAC	10
2	PFA	Jordan Aquifer	Single-Use IX Resin	10
3	F400	Shakopee Aquifer	Bituminous GAC	10
4	PFA	Shakopee Aquifer	Single-Use IX Resin	10
5	F400	WCL	Bituminous GAC	10
6	PFA	WCL	Single-Use IX Resin	10
7	F400	SAFF® Treated Shakopee Aquifer	Bituminous GAC	10
8	PFA	SAFF® Treated Shakopee Aquifer	Single-Use IX Resin	10
Total Samples				80

Influent water was filtered with a 1-µm polyethersulfone/polypropylene filter to remove any particles that could damage the RSSCT system. These filters have previously been used and tested for PFAS treatability experiments by AECOM and are allowed in terms of PFAS compatibility by the 2018 General PFAS Sampling Guidance (MDEQ, 2018). The RSSCT procedure was based on the ASTM D6586 methodology with slight variations, such as the length of the column, to optimize the duration of the test. The RSSCT procedure steps are summarized as follows:

- Determine sorbent particle size via ASTM D2862 method;
- Measure ground particle size using a Microtrac laser diffractor (instrument particle diameter range of 0.025 µm to 1,400 µm);
- Assemble and pack RSSCT columns;
- Sample effluent and monitor flowrate; and
- Collect final samples and ship to analytical laboratory.

H4.1.1 Treatment Criteria

The treatment criteria considered included the 2024 United States Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs), MPCA Site-Specific Water Quality Criteria (SSC), Minnesota Department of Health (MDH) Health Risk Limits (HRLs), MDH Health-Based Values (HBVs), and MDH Health Risk Indexes (HRIs). EPA MCLs have been promulgated for perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorobutane sulfonic acid (PFBS), and hexafluoropropylene oxide-dimer acid (HFPO-DA). MDH HRLs and HBVs and MPCA SSC similarly regulate PFOS, PFOS, PFHxS, PFBS levels, but also include perfluorohexanoic acid (PFHxA) and perfluorobutanoic acid (PFBA).

The Hazard Index (HI), a dimensionless, calculated value based on the weighted concentrations of PFNA, PFHxS, PFBS, and HFPO-DA, was also considered. The equation for the HI is given below, and more information on the HI calculation can be found in Section 9 of the FS.

$$HI = \frac{[HFPO - DA]\ ng/L}{10\ ng/L} + \frac{[PFBS]\ ng/L}{2000\ ng/L} + \frac{[PFNA]\ ng/L}{10\ ng/L} + \frac{[PFHxS]\ ng/L}{10\ ng/L}$$

HRLs and HBVs are Minnesota-specific standards that must also be considered. While HRLs have been formalized in Minnesota rules, HBVs have not yet been promulgated. This distinction is important, as the Cancer HBV for PFOA is 0.0079 nanograms per liter (ng/L), which is significantly below current detection limits. Thus, the groundwater HBV, which is 0.24 ng/L, is used for comparison as this is closer to current analytical detection limits.

MDH has also developed a Health Risk Index (HRI) that calculates an additivity value for multiple PFAS compounds. Additivity is considered for every health endpoint for which MDH has developed an HRL or HBV. For PFAS, these health endpoints in the liver system, immune system, developmental, kidney system, thyroid (specifically the endocrine mediated effect on the thyroid), and cancer. Additivity is further evaluated based on exposure duration, with durations specified as acute, short-term, sub-chronic, chronic, and cancer. In the case of PFAS species, regulated by MDH, no species have acute standards, and all short-term, sub-chronic, and chronic values are the same with a compound.

HRIs must be considered in this analysis. Equations for calculation of the five HRIs are given below. For the purposes of this report, only the thyroid HRI was evaluated as the other four (developmental, liver system, immune system, and kidney system) include PFOA, and developmental, liver system, and immune system HRIs include PFOS. As current method detection limits for PFOA and PFOS are on the order of 1-2 ng/L, functionally any breakthrough of PFOA and PFOS would cause exceedance of either the relevant HRIs along with MDH HRLs and HBVs for PFOA and PFOS. Should instrument detection limits be lowered to less than 0.1 ng/L, that would change this analysis. At this time, any detection of

PFOA and PFOS is considered to require a media changeout. Thus, only the thyroid HRI, which incorporates MDH standards for PFHxA, PFHxS, PFBA, and PFBS, was calculated in this report.

$$Developmental\ HRI = \frac{[PFOA]\ ng/L}{0.24\ ng/L} + \frac{[PFOS]\ ng/L}{2.3\ ng/L} + \frac{[PFHxA]\ ng/L}{200\ ng/L}$$

$$Liver\ System\ HRI = \frac{[PFOA]\ ng/L}{0.24\ ng/L} + \frac{[PFOS]\ ng/L}{2.3\ ng/L} + \frac{[PFHxS]\ ng/L}{10\ ng/L} + \frac{[PFBA]\ ng/L}{7000\ ng/L}$$

$$Immune\ System\ HRI = \frac{[PFOA]\ ng/L}{0.24\ ng/L} + \frac{[PFOS]\ ng/L}{2.3\ ng/L}$$

$$Thyroid\ HRI = \frac{[PFHxA]\ ng/L}{200\ ng/L} + \frac{[PFHxS]\ ng/L}{10\ ng/L} + \frac{[PFBA]\ ng/L}{7000\ ng/L} + \frac{[PFBS]\ ng/L}{100\ ng/L}$$

$$Cancer\ HRI = \frac{[PFOA]\ ng/L}{0.0079\ ng/L} + \frac{[PFOS]\ ng/L}{7.6\ ng/L}$$

The most appropriate limits were chosen for each analyte based on the water source; regulatory limits are listed in Table H.11 in ng/L. These concentration thresholds were used to determine breakthrough concentrations for each compound in the RSSCT effluent samples.

SSC are only applicable for discharge to surface water in specific areas. Should a pump and treat system be built at WCL, it is unknown how the water would be discharged, as there are several potential alternatives that could be pursued. For the purposes of this report, discharge to surface water was assumed, thus SSC are used for WCL RSSCTs.

Table H.11: Selected Effluent Threshold Limit Criteria.

Analyte (Acronym)	Units	EPA MCL	2024 HRL & HBV	SSC	Jordan Aquifer	Shakopee Aquifer	SAFF® Treated Shakopee Aquifer	WCL
PFBA	ng/L	-	7,000 (d)	5,700	HRL	HRL	HRL	SSC
PFOA	ng/L	4	0.24 (b)	25	HBV	HBV	HBV	SSC
			35 (d)					
PFBS	ng/L	2000 (a)	100 (d)	140	HRL	HRL	HRL	SSC
PFHxA	ng/L	-	200 (d)	220	HRL	HRL	HRL	SSC
PFHxS	ng/L	10 (a)	47 (d)	20	MCL	MCL	MCL	SSC
PFOS	ng/L	4	2.3 (b)	0.05	HBV	HBV	HBV	SSC
			300(c)					
HFPO-DA	ng/L	10 (a)	-	-	MCL	MCL	MCL	MCL
HI	-	1.0	-	-	MCL	MCL	MCL	MCL
Thyroid HRI	-	-	1	-	HRI	HRI	HRI	HRI
PFNA	ng/L	10 (a)	-	-	MCL	MCL	MCL	MCL

(a) Health-Based Water Concentration;
(b) HBV = Health-Based Values, short term/subchronic/chronic;
(c) HRL = Health Risk Limit, chronic;
(d) HRL, short term.

H4.1.2 Test Design and Procedures

The test apparatus consisted of a feed reservoir connected to a high-performance liquid chromatography (HPLC) pump by polyetheretherketone (PEEK) tubing as shown in Figure H.6. The HPLC pump sends the influent water to the inlet of the column. The water flow is distributed through a layer of glass wool, then enters the sorbent bed. Before exiting the column, the water passes through another layer of glass wool. The effluent is discharged to a waste container using PEEK tubing. This effluent tube is switched to a new HDPE bottle to collect water during sampling.

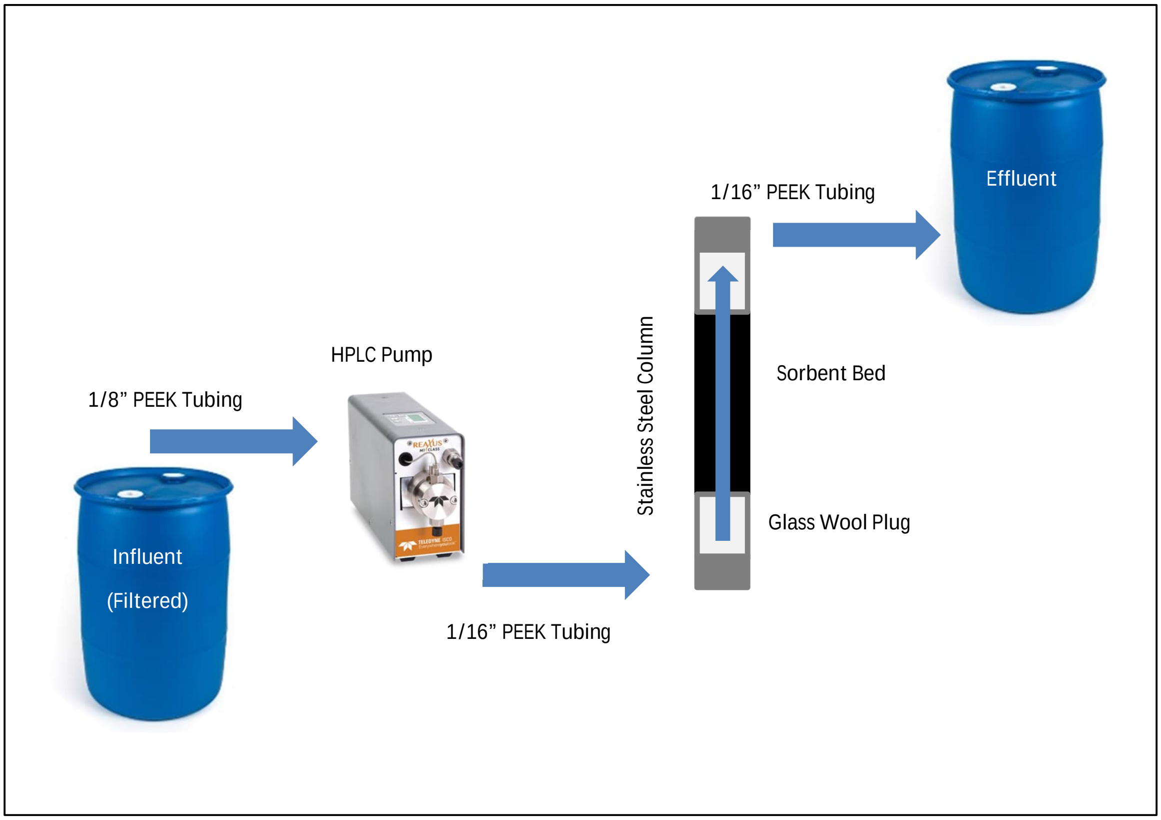

Figure H.6: Schematic of Rapid Small-Scale Column Test with Directional Flows.

The RSSCTs were designed following the constant diffusivity model. The design parameters for the small-scale columns are flowrate, empty bed contact time (EBCT) (1), surface loading rate (SLR) (2), and small-scale particle size (e.g. mean particle diameter). These design parameters were obtained based on the simulated full-scale parameters, including as-manufactured sorbent particle size and expected full-scale EBCT. Industry standards and manufacturer-provided information were used to select EBCTs for media; three minutes was selected for IX resin tests and 10 minutes was selected for GAC tests. The final RSSCT design parameters are listed in Table H.12. Note that while the targeted bed volumes were the same for both media, F400 tests were run for a longer time duration than PFA tests. Additionally, a larger volume of water was used for GAC tests than IX tests. This is due to the difference in column size, as a shorter column was used for IX tests than GAC tests, due to the differences in scaling factor and

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(1) Empty Bed Contact Time is calculated by dividing the volume of a treatment vessel by the flow rate through the vessel, giving a theoretical treatment time for liquid that passes through the vessel. It assumes all liquid moves at the same velocity. EBCT provides a comparison between media types for the relative amount of time a liquid must be in contact with a treatment media to reach treatment objectives. A longer EBCT requires a larger vessel. Adsorptive media that requires a shorter EBCT is preferable, as smaller vessels can be purchased, and less building footprint is needed, reducing the cost of projects.

(2) Surface Loading Rate (SLR) is a measure of volume of water treated per surface area of the treatment media. SLR is calculated by divided the flow through a vessel by the surface area of the vessel and is often given in gallons per minute per square foot. Proper SLR is needed to prevent channeling (creation of preferential pathways through a media) and to prevent overloading of the media.

EBCT. As the targeted bed volumes were the same, specific throughputs could be calculated to allow direct comparison of results to each other.

Table H.12: RSSCT Design Parameters.

Parameter	Units	Sorbent	
		F400	PFA
Large-Scale EBCT	min	10	3
Large-Scale Sorbent Particle Size	cm	0.0937	0.0700
Small-Scale Sorbent Particle Size	cm	0.0101	0.0101
Scaling Factor (small/large particle)	--	0.012	0.021
Small-Scale SLR	cm/s	0.25	0.25
Small-Scale EBCT	min	0.12	0.06
Small-Scale Carbon Bed Length	cm	1.75	0.94
Target Bed Volumes to Treat	--	100,000	100,000
Small-Scale Flowrate	mL/min	2.50	2.50
Minimum Test Duration	days	8.1	4.3
Volume of Water Treated per Column	gal	7.7	4.1
Reynolds Number (Re)	--	0.505	0.505

Legend: cm = centimeters; cm/s = centimeters per second; min = minutes.

During RSSCTs, test columns for GAC and IX tests drew water from the same influent sample container. Three influent samples were collected during RSSCT operations: at time zero (T_0), at a mid-point during the test (T_{mid}), and at the endpoint (T_{end}). Ten effluent samples were collected from each column over the duration of the test, and all samples were analyzed for PFAS compounds by SGS AXIS and TOC by Pace.

Effluent flowrate was monitored by dividing the amount of effluent sample collected in a container by recording the time of collection. Monitoring of water quality parameters (pH, ORP, and EC) was performed using a Hach® benchtop meter (Model HQ430d) and probes for each analyte after collecting small effluent aliquots (5 to 10 mL total). Turbidity measurements required a 20 mL per sample and were conducted using a Hach® benchtop turbidity meter (Model 18900). PFAS and TOC influent samples were collected and sent to the outside laboratories for analysis; these analyses required 640 mL sample, equivalent to a range of 2,206 - 4,102 effluent bed volumes depending on the sorbent bed volume. Effluent samples for general chemistry analyses were collected at the beginning and end of the test and were also sent to the outside laboratory.

H4.2 RSSCT Results

Influent and effluent samples from the RSSCTs were collected for off-site PFAS and TOC analysis along with samples for pH, ORP, EC, etc. determination by AECOM staff. Detailed results are arranged on a time basis with the volume of water treated (bed volumes) and the specific throughput (liters of water per kilogram of sorbent [L/kg]) also being presented. The totality of these results is presented in Section H8.2.

Results from samples collected during the RSSCT tests were initially evaluated by generating two types of plots for each PFAS compound. One set of plots showed concentration vs bed volumes and the other showed concentration vs specific throughput. Section H8 represents the plots for all PFAS compounds that had detections in the influent samples.

The following sections segregate the results of the RSSCT tests by influent water source. Each section presents plots for only a few of the compounds to illustrate the way the data were evaluated in detail and to support conclusions of this report. Breakthrough plots are presented as concentration versus specific throughput in L/kg. Results from samples collected during the RSSCT tests were ultimately evaluated to determine breakthrough concentrations for each sorbent. Assuming a lead-lag vessel configuration, there are typically two aspects of the full-scale treatment for which breakthrough criteria need evaluated: 1) the effluent discharged from the treatment system (lag vessel) that should meet a regulatory threshold value, and 2) the effluent from the lead vessel to anticipate when a media changeout would need to occur, often based on the percent of media saturation (e.g., 5% or 50% of the influent concentration).

For this study, the selected treatment criteria were used as the regulatory threshold value for the effluent of the lead vessel and as media changeout criteria. As discussed in Section H4.1.1 these regulatory criteria included a combination of promulgated EPA MCL's and MDH HRLs, HBVs, and HRIs, and MPCA SSC limits. Regulated PFAS compounds of interest are PFOA, PFOS, PFHxS, PFBA, PFHxA, and PFBS, as well as the EPA HI and MDH HRIs, specifically the Thyroid HRI, as previously discussed. According to RSSCT ASTM methodology (ASTM 2014), the additional following metrics were obtained to evaluate performance of the media.

- RSSCT bed life = time to specified breakthrough level (based on the EPA MCLs)
- Treatable bed volumes = total volume until breakthrough/actual bed volume
- Total volume of water fed to RSSCT until breakthrough
- Specific throughput = total volume fed to RSSCT/sorbent mass
- Sorbent usage rate = 1/specific throughput
- Length of mass transfer zone (MTZ) using the time to 5% breakthrough level, time to 95% breakthrough level, time to full breakthrough, and the length of the column (calculated only for the rate-limiting PFAS compound).

H4.2.1 Jordan Aquifer Groundwater Results

H4.2.1.1 Total PFAS Results

Total PFAS, a summation of the concentrations of all detected PFAS compounds by EPA Method 1633, was calculated for the influent and column effluents and is given in Figure H.7. The Total PFAS concentration in the PFA IX column effluent was always less than that of the F400 GAC column and the influent for the duration of the test. This demonstrates better overall performance of the adsorption of the PFA IX sorbent, as fewer compounds broke through during the RSSCT and at lower concentrations, compared to the GAC.

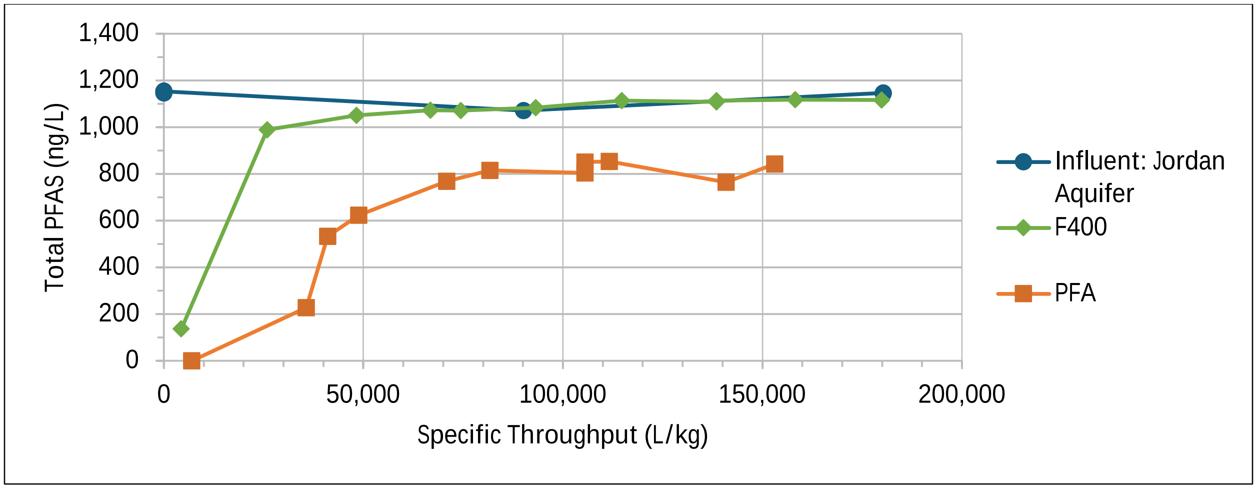

Figure H.7: Total PFAS Concentrations for Jordan Aquifer Effluent Samples.

H4.2.1.2 Hazard Index Results

The initial influent value of the HI was 2.45, exceeding the regulatory limit of 1.0 (Figure H.8). Samples analyzed during the RSSCT show that the PFA sorbent kept the HI below 1.0 for the entirety of the test, with a maximum value of 0.25. The F400 GAC, however, exceeded an HI of 1.0 at an estimate specific throughput of 25,000 L/kg. By the end of the test, the F400 effluent HI was the same level as the influent, indicating media saturation.

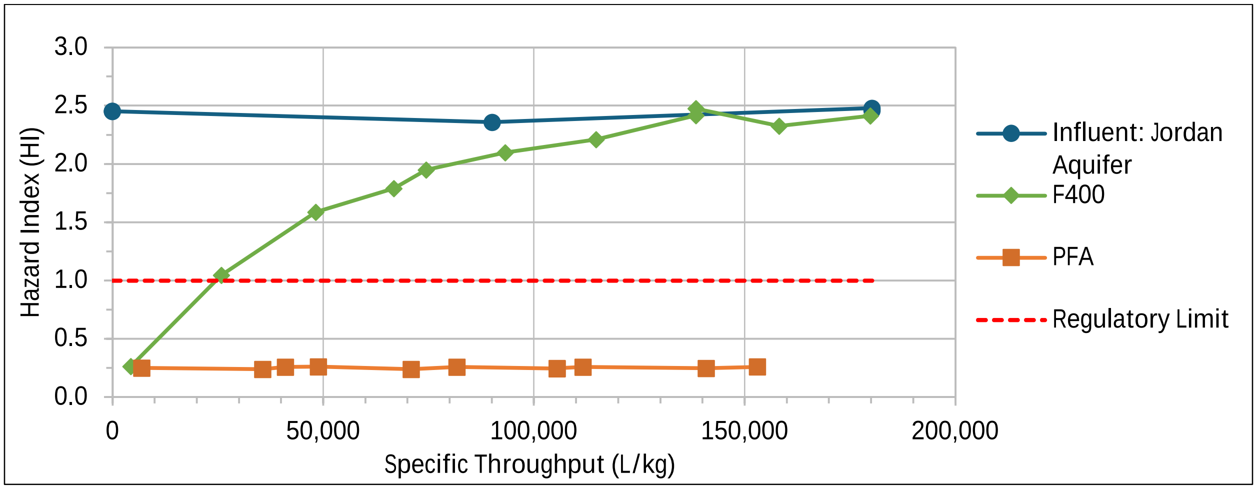

Figure H.8: Hazard Index of Regulated PFAS Concentrations for Jordan Aquifer Effluent Samples.

H4.2.1.3 Thyroid Health Risk Index Results

The initial influent value averaged 1.73, exceeding the Thyroid HRI limit of 1.0 (Figure H.9). Similar to the HI, the PFA sorbent was below the limit for the entirety of the test, while F400 GAC exceeded the threshold at specific throughput of about 90,000 L/kg.

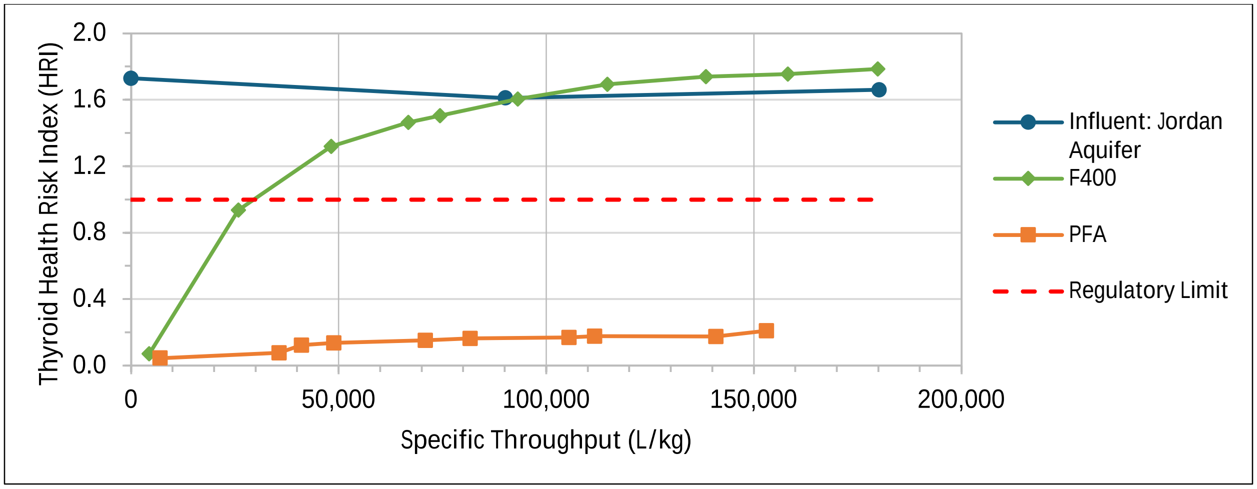

Figure H.9: Thyroid Health Risk Index for Jordan Aquifer Effluent Samples.

H4.2.1.4 Regulated PFAS Compounds

PFAS compounds that are regulated by the EPA and MDH were monitored in effluent samples and compared to the selected treatment criteria. In the Jordan Aquifer groundwater, the concentrations of the following compounds did not exceed regulatory limits in the influent: PFBA (Figure H.10), PFHxA (Figure H.11), and PFBS (Figure H.12). Even though these compounds broke through quickly to reach the concentrations in influent samples, individually they are not used to evaluate the performance of the sorbent on the Jordan Aquifer groundwater, as they never exceeded the regulatory limits. However, this breakthrough will be considered when discussing the potential decrease of these regulatory limits in the future.

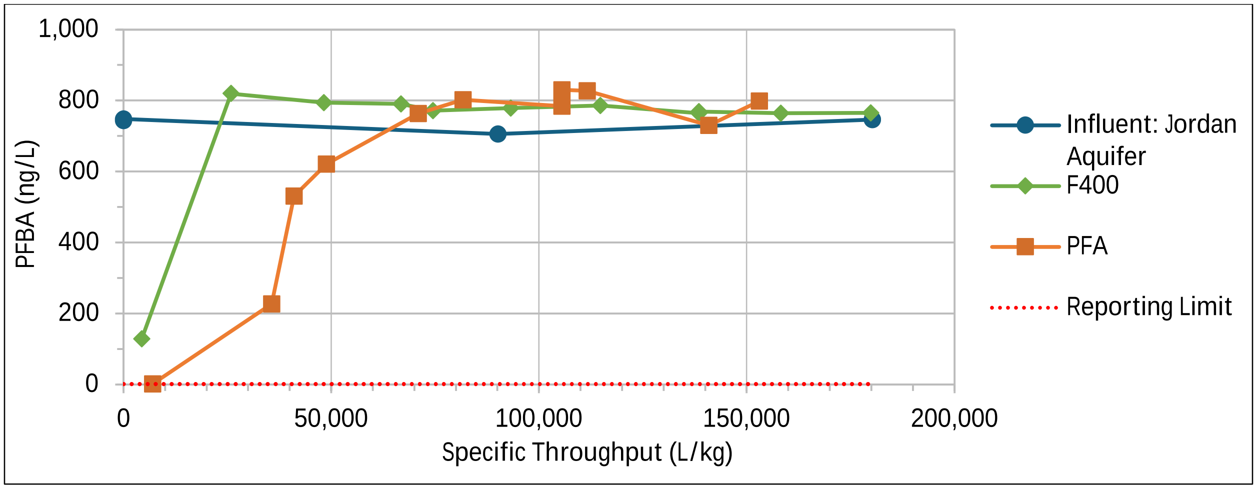

Figure H.10: PFBA Concentrations for Jordan Aquifer Effluent Samples.

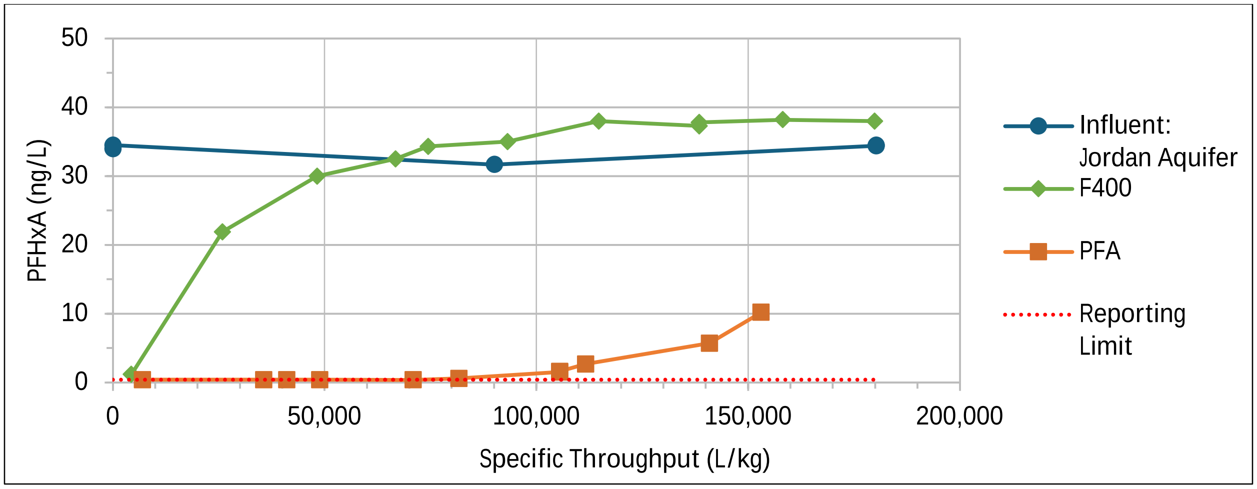

Figure H.11: PFHxA Concentrations for Jordan Aquifer Effluent Samples.

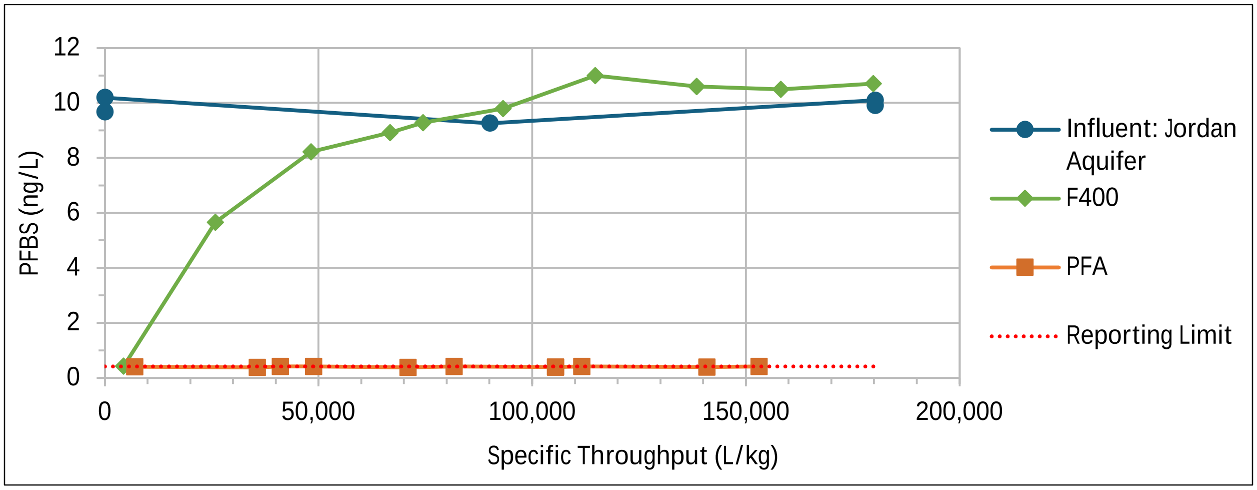

Figure H.12: PFBS Concentrations for Jordan Aquifer Effluent Samples.

The MDH HBV for PFOA is 0.24 ng/L, which is below the laboratory method reporting limit of 0.4 ng/L. Therefore, the first detection of PFOA was used to determine when the effluent of a column exceeded the regulatory limit. The Jordan Aquifer groundwater influent had a PFOA concentration of 163 ng/L, well above the HBV limit (Figure H.13). PFOA was first detected at a specific throughput of 4,364 L/kg in the F400 GAC effluent at a concentration of 70.3 ng/L. The PFA sorbent effluent did not have a detection of PFOA for the duration of the test.

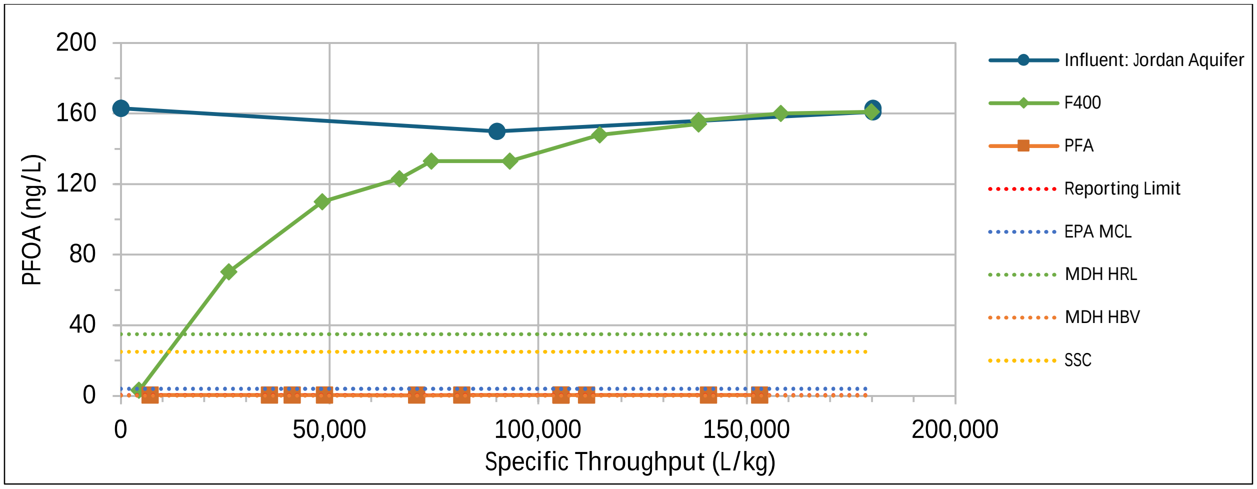

Figure H.13: PFOA Concentrations for Jordan Aquifer Effluents.

Similarly, PFHxS (Figure H.14) and PFOS (Figure H.15) were not detected in the PFA column effluent during the test. In the F400 column effluent, these compounds exceeded the MCL for PFHxS of 10 ng/L and the HBV of PFOS of 2.3 ng/L at a specific throughput of approximately 38,000 L/kg and 5,000 L/kg, respectively. By the end of the F400 column test, the effluent PFHxS concentration reached that of the influent at 19.9 ng/L.

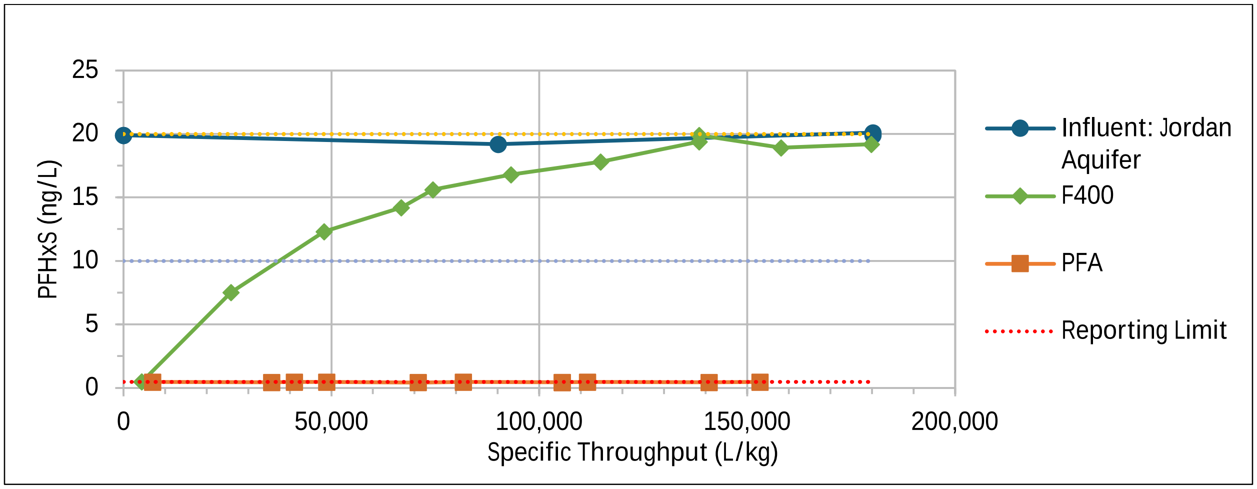

Figure H.14: PFHxS Concentrations for Jordan Aquifer Effluent Samples.

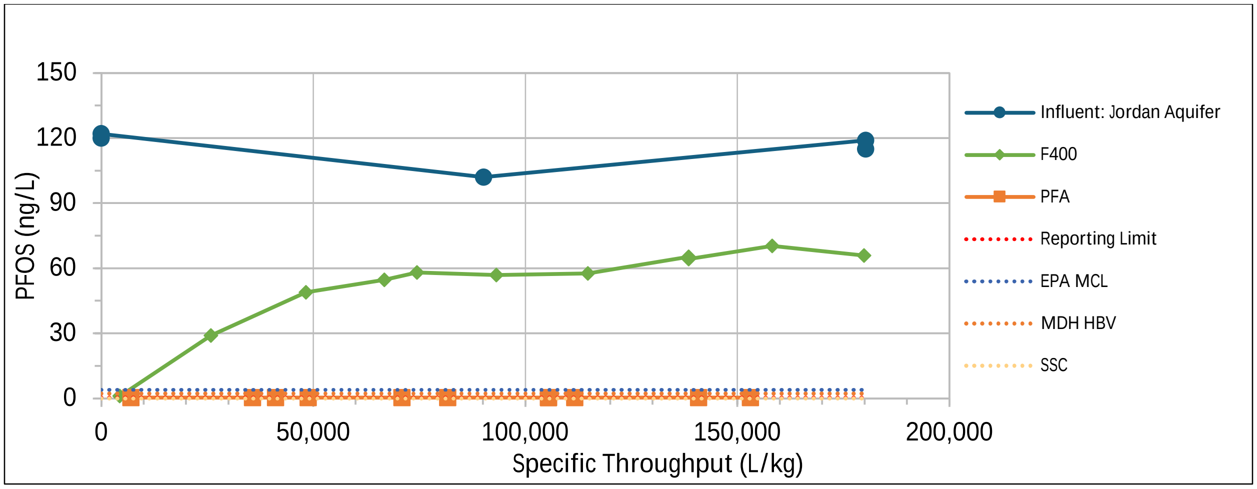

Figure H.15: PFOS Concentrations for Jordan Aquifer Effluent Samples.

H4.2.1.5 Specific Throughputs at Breakthrough

The breakthrough of a regulated PFAS compound was determined to be when the concentration of the compound in the effluent exceeded the selected treatment criteria regulatory limit. For this study, breakthroughs are presented as specific throughputs which indicate the volume of water treated per mass of sorbent packed in a column. Specific throughput is more scalable to large-scale systems compared to bed volumes. A summary of the specific throughputs at which all columns reached breakthrough for the regulated PFAS compounds is shown in Table H.13. In addition, the MTZ for the limiting PFAS compound (PFOA) was calculated for the F400 GAC, as this media achieved full saturation.

Table H.13: Summary of Specific Throughputs at Breakthrough for Jordan Aquifer.

Criterion	Units	F400 GAC	PFA IX Resin
Based on MDH HBV PFOA = 0.2 ng/L	L/kg	4,364	>153,068
Based on MDH HBV PFOS = 2.3 ng/L	L/kg	5,000	>153,068
Based on EPA MCL PFHxS = 10 ng/L	L/kg	18,000	>153,068
Based on MDH HRL PFBA = 7000 ng/L	L/kg	>179,847	>153,068
Based on MDH HRL PFHxA = 200 ng/L	L/kg	>179,847	>153,068
Based on MDH HRL PFBS = 100 ng/L	L/kg	>179,847	>153,068
Based on MCL HI = 1.0	L/kg	25,000	>153,068
Based on Thyroid HRI = 1.0	L/kg	27,631	>153.569
Minimum Specific Throughput	L/kg	4,364	>153,068
MTZ (based on PFOA)	cm	1.44	NA (1)
MTZ Relative	%	82%	NA

(1) MTZ could not be calculated for PFA as breakthrough of regulated compounds was not observed.

In overall adsorption, the PFA IX resin performed better than the F400 GAC. All regulated compounds were kept below regulated limits for the entirety of test. For the IX resin. This suggests that one kg of the PFA IX resin could be used to successfully treat a minimum of 153,068 L of Jordan Aquifer groundwater using the same conditions as the RSSCT.

The F400 column saw a breakthrough during the test in all compounds except those that were not present above regulated concentrations in the influent. PFOA was the first compound to surpass its regulatory limit, and it was first detected at a specific throughput 4,364 L/kg. This is likely due to the more stringent requirements for PFOA when compared to the MDH HBV for PFOS and the EPA MCL for

PFHxS. PFOA is also a carboxylic acid with less sorption affinity compared to sulfonated PFAS such as PFOS and PFHxS.

H4.2.1.6 Mass Transfer Zone Calculations

The MTZ of a sorbent was calculated for the rate-limiting PFAS compound in the column effluent. For the Jordan Aquifer groundwater, PFOA was the first compound to achieve breakthrough from the F400 GAC column. The MTZ for F400 was 1.44 cm, or 82% of the entire bed depth (Table H.13). This is considered a large MTZ value. A MTZ could not be calculated for the PFA IX resin, as none of the regulated PFAS compounds exceeded regulatory limits or the influent concentrations.

H4.2.1.7 Other Notable Results

The TOC concentrations for the Jordan Aquifer influent water and treated effluents are summed in Figure H.16. Influent concentrations hovered between 1.9 mg/L to 2.0 mg/L for the entire duration of the test. TOC concentrations for the F400 effluents were initially undetected at the first sample but gradually increased towards 1.5 mg/L midway through the test before stabilizing at 1.6mg/L to 1.7 mg/L towards the end of the test. The PFA column had similar effectiveness, with lower (1.3 mg/L) concentrations at the beginning of the test before saturating towards 1.6 g/L to 1.7 mg/L towards the end of the test.

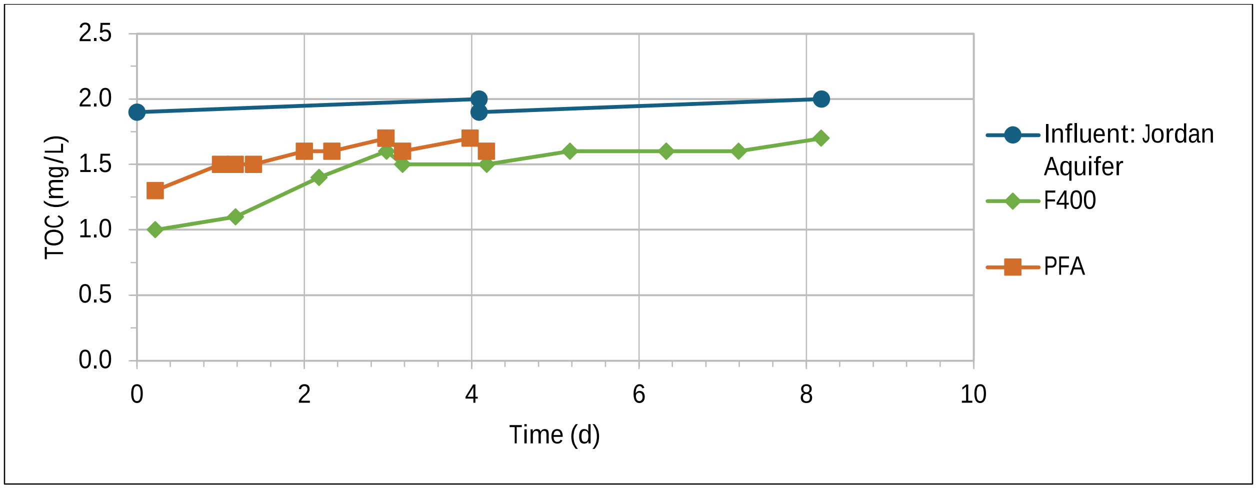

Figure H.16: TOC Concentrations for Jordan Aquifer Effluent Samples.

Turbidity for Jordan Aquifer effluent and influent samples stayed relatively low during the entire duration of the test (Figure H.17). The influent water averaged 0.36 NTU while F400 effluent initially started at 0.29 NTU before gradually rising 0.75 NTU by the end of the test. The PFA effluent samples fluctuated between 0.26 NTU and 0.60 NTU throughout the test.

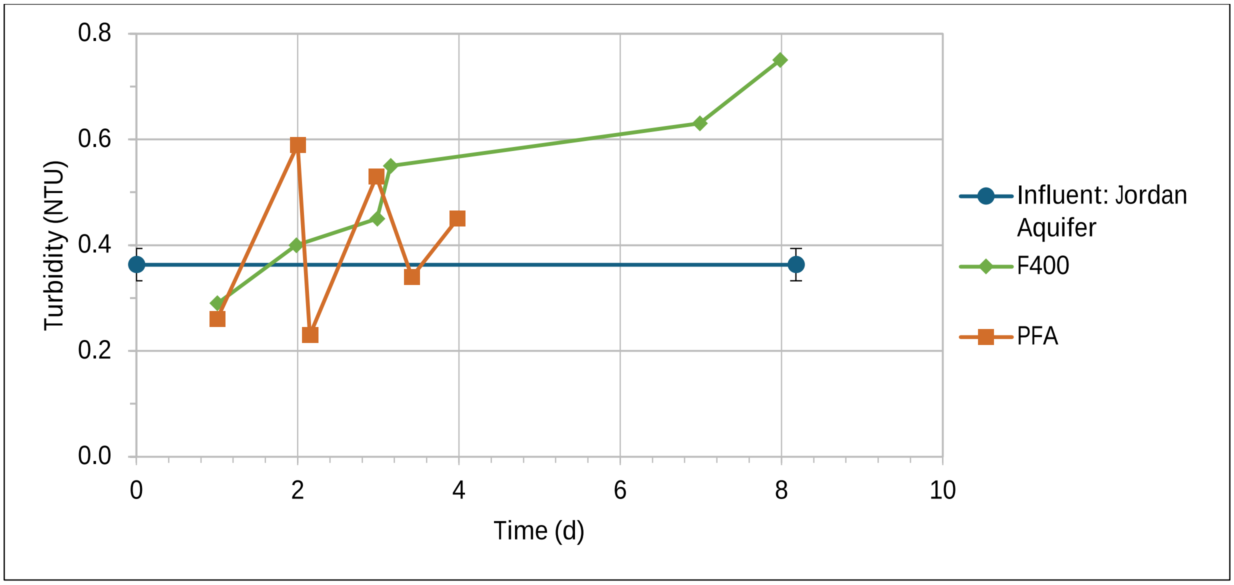

Figure H.17: Turbidity Results for Jordan Aquifer Effluent Samples.

Water quality and operational parameters like flowrate, ORP, pH, and EC trends were tracked for Jordan Aquifer influent and effluent samples (Figure H.18). The flowrate for the PFA column stayed on target (2.5 mL/min) through the duration of test. The F400 column flow rate was mostly consistent to target until the end of the test, where the flowrate dropped to 1.79 mL/min due to partial column clogging. The ORP for both column effluents stayed slightly higher than the influent average of 384.43 millivolts (mV). F400 ORP fluctuated between 391.7 mV to 440.8 mV while PFA effluent stayed between 403 mV to 452 mV. The influent pH averaged to 7.96. The F400 column's pH started at 7.9 and increased gradually to 8.2 towards the end of the test. The PFA column's pH initially started at 7.46 before sharply increasing 7.94 before gradually reaching 8.13 by the end of the test. PFA's EC results initially started at 432.5 µS/cm before spiking to 587.3 µS/cm and dropping towards to more influent levels of 350s. F400 EC levels stayed consistent with the influent's average throughout the duration of the test.

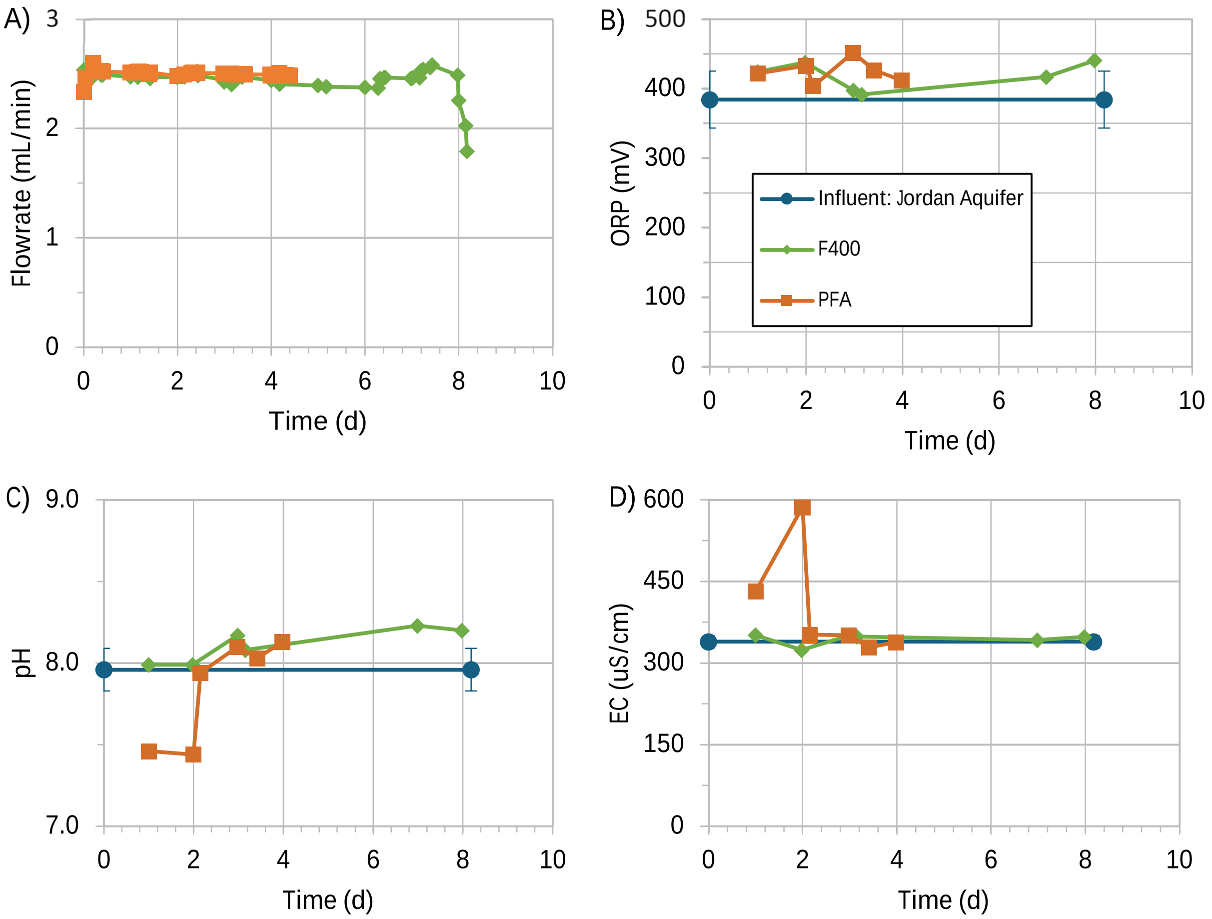

Figure H.18: A) Flowrate, B) ORP, C) pH, and D) EC Results for Jordan Aquifer Effluent Samples.

Water chemistry results for inorganic constituents including alkalinity, hardness, anions, total and dissolved metals, total suspended and dissolved solids for Jordan Aquifer samples are presented in Table H.14. Alkalinity and total hardness concentrations between the influents and column effluents stayed relatively equal, with alkalinity concentrations ranging between 131 mg/L to 139 mg/L and hardness concentrations at 143 mg/L to 149 mg/L. Anion concentrations for chloride, nitrate, and sulfate remained consistent throughout the test between the effluents and influent samples. Total and dissolved iron concentrations remained undetected in the influent and effluents, while magnesium and calcium concentrations for total and dissolved samples remained unchanged throughout the test. Both PFA and F400 final effluent samples saw undetected concentrations of total manganese while the influent manganese concentration ranged from 0.61 microgram per liter (µg/L) to 0.86 µg/L throughout the test. Dissolved manganese remained undetected for all effluent samples and most influent samples other than the final influent sample (0.9 µg/L). Both columns had higher final TSS concentrations than the influent samples, with the F400 column having a final concentration of 1.84 mg/L TSS while PFA's was 3.16 mg/L. The influent's TSS remained <1.00 mg/L throughout the duration of the test. TDS concentration was similar across the influents and effluent samples, ranging from 79.1 mg/L to 84.6 mg/L.

Table H.14: General Water Chemistry and Metals Concentrations for Jordan Aquifer.

Parameter	Units	Influent Samples			F400 Effluent		PFA Effluent	
		Initial	Middle	Final	Initial	Final	Initial	Final
Alkalinity, Total as $CaCO_3$	mg/L	138	138	131	137	139	139	138
Total Hardness	mg/L	149	149	141	143	146	147	143
Chloride	mg/L	26.2	26.55	25.8	-	25.8	-	27.6
Nitrate as Nitrogen	mg/L	0.8	0.82	0.77	-	0.76	-	0.84
Sulfate	mg/L	5.3	5.3	5.3	-	5.1	-	5.3
Calcium	mg/L	30.7	30.5	28.7	-	29.6	-	29.1
Iron	µg/L	<50	<50	<50	-	<50	-	<50
Magnesium	mg/L	17.7	17.8	16.9	-	17.4	-	17.1
Manganese	µg/L	0.85	0.86	0.61	-	<0.5	-	<0.5
Calcium, Dissolved	mg/L	31.5	27.9	29.7	-	28.9	-	31.4
Iron, Dissolved	µg/L	<50	<50	<50	-	<50	-	<50
Magnesium, Dissolved	mg/L	18.1	16.1	16.9	-	16.6	-	18.0
Manganese, Dissolved	µg/L	<0.5	<0.5	0.9	-	<0.5	-	<0.5
TSS	mg/L	0.43	0.45	0.21	-	1.84	-	3.16
TDS	mg/L	79.1	83.4	84.6	-	81.2	-	82.7

H4.2.2 Shakopee Aquifer Groundwater Results

H4.2.2.1 Total PFAS Results

Total PFAS concentration was calculated for influent and effluents samples and are given in Figure H.19. The PFA column was able to remove more PFAS from the influent than the F400 GAC column, as shown by a lower total PFAS concentration for the duration of the test. However, both sorbent columns were effective at keeping the total PFAS concentration below that of the influent for the entire test.

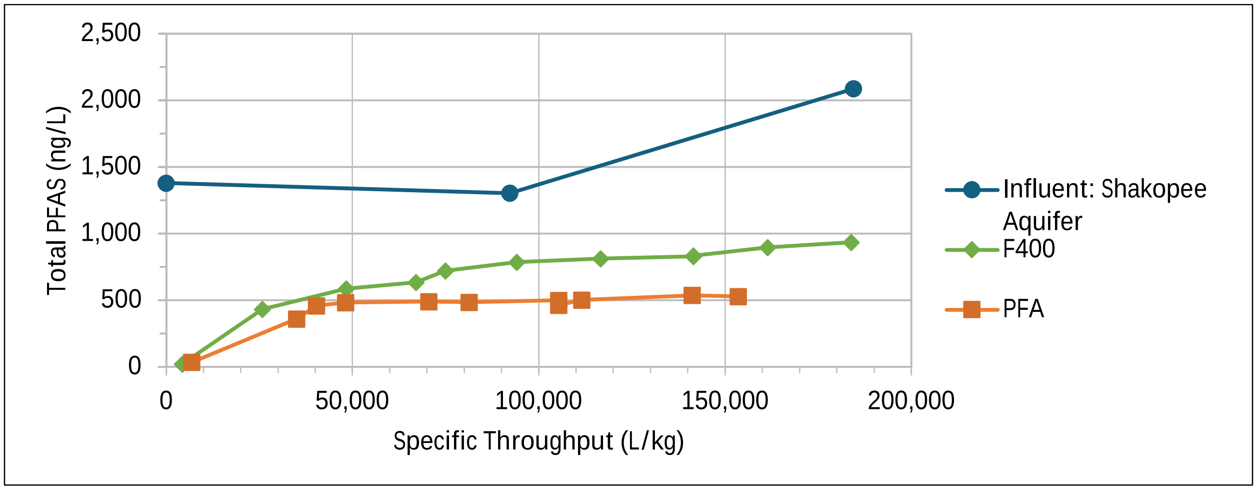

Figure H.19: Total PFAS Concentrations for Shakopee Aquifer Effluent Samples.

H4.2.2.2 Hazard Index Results

The HI regulatory limit of 1.0 was exceeded in the influent, which had an HI of 4.17 (Figure H.20). Samples analyzed during the RSSCT show that the PFA sorbent kept the HI below 1.0 for the entirety of the test, with a maximum value of 0.27. The F400 GAC, however, exceeded an HI of 1.0 at an estimate specific throughput of 57,000 L/kg. By the end of the test, the F400 effluent HI did not reach the influent value.

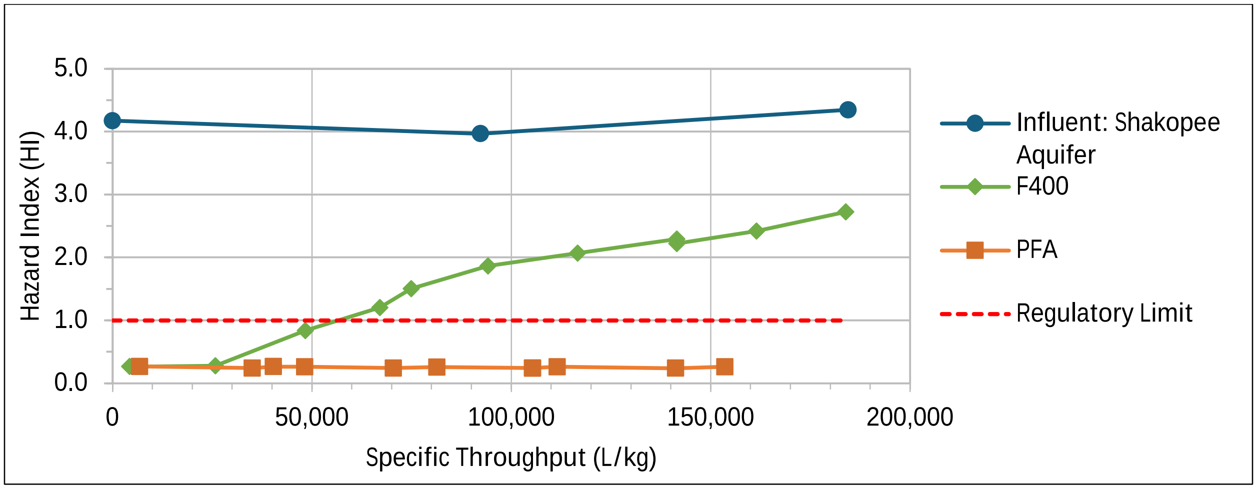

Figure H.20: Hazard Index of Regulated PFAS Concentrations for Shakopee Aquifer Effluent Samples.

H4.2.2.3 Thyroid Health Risk Index Results

The Shakopee Aquifer had a thyroid HRI 3.5 times higher than the 1.0 limit (Figure H.21). The PFA sorbent did not reach the thyroid HRI over the course of the test but was near the limit at 0.95 after a specific throughput of 153,569 L/kg. The F400 GAC reached saturation at a specific breakthrough of approximately 48,000 L/kg.

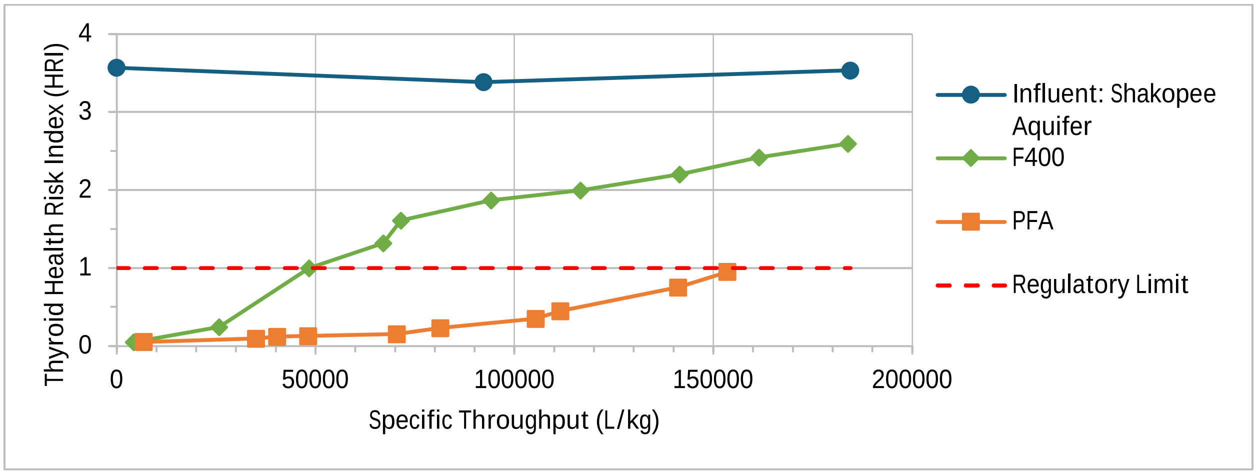

Figure H.21: Thyroid Health Risk Index for Shakopee Aquifer Effluent Samples.

H4.2.2.4 Regulated PFAS Compounds

PFAS compounds that are regulated by the EPA and MDH were monitored in effluent samples and compared to the selected treatment criteria. In the Shakopee Aquifer samples, the concentrations of the following compounds did not exceed regulatory limits in the influent: PFBA (Figure H.22), PFHxA (Figure H.23), and PFBS (Figure H.24). Even if these compounds broke through quickly to reach the concentrations in the influent, they were not used to evaluate the performance of the sorbent on the Shakopee Aquifer groundwater as they are not in exceedance of current regulatory limits.

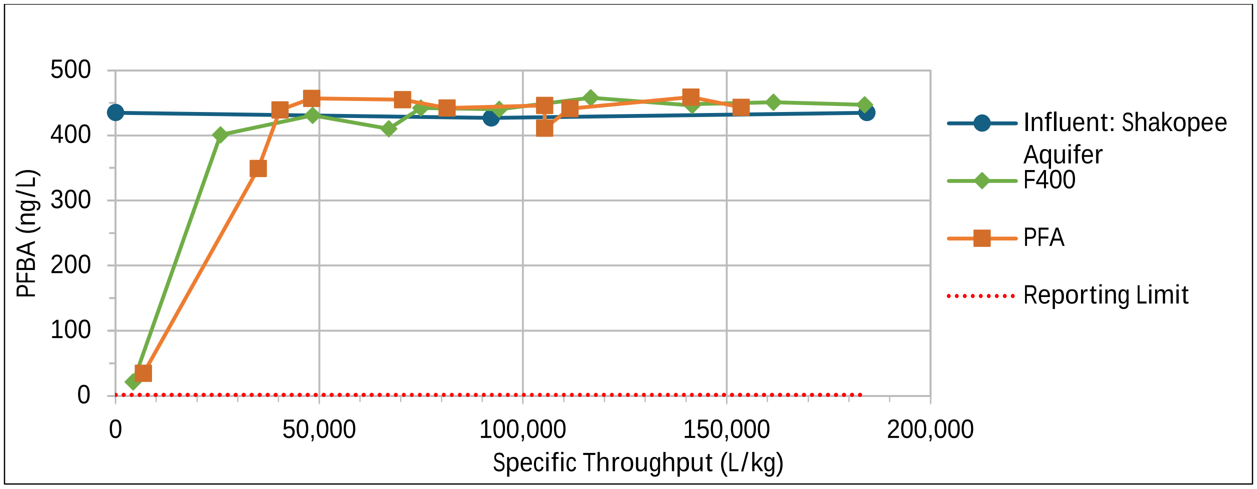

Figure H.22: PFBA Concentrations for Shakopee Aquifer Effluent Samples.

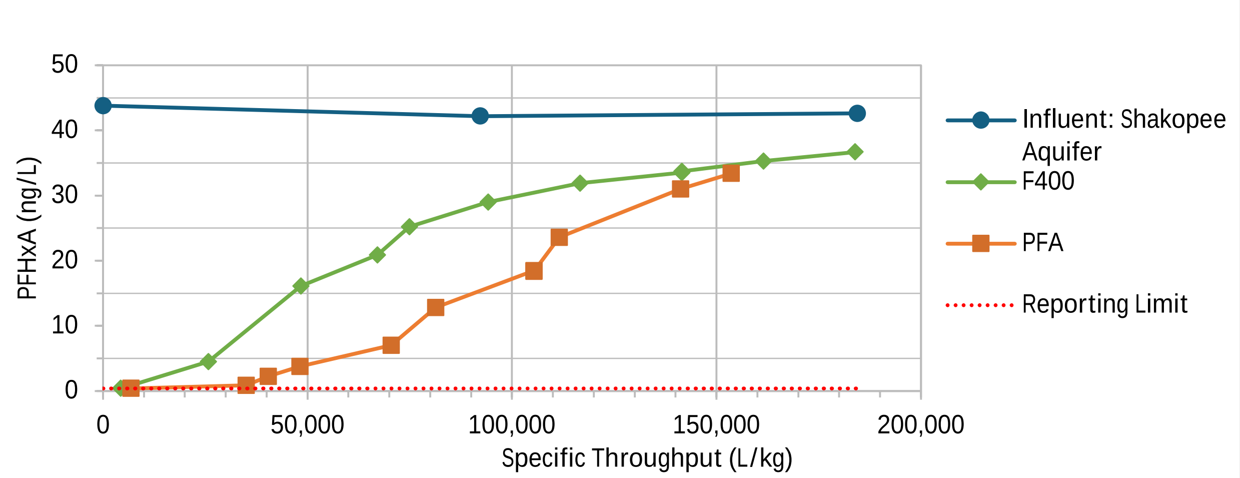

Figure H.23: PFHxA Concentrations for Shakopee Aquifer Effluent Samples.

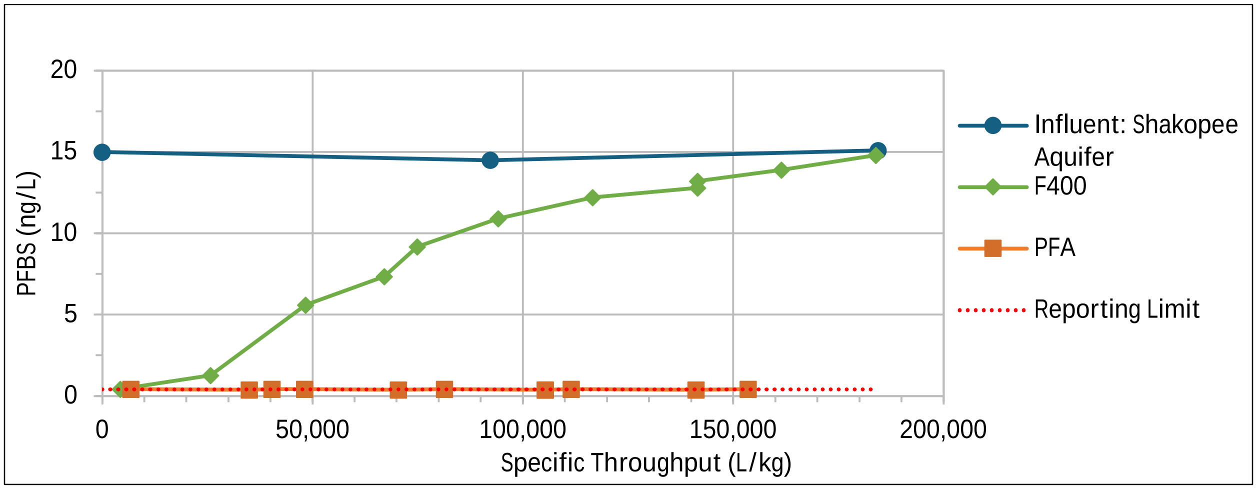

Figure H.24: PFBS Concentrations for Shakopee Aquifer Effluent Samples.

The MDH HBV for PFOA is 0.2 ng/L, which is below the laboratory method reporting limit of 0.4 ng/L. Therefore, the first detection of PFOA was used to determine when the effluent of a column exceeded the regulatory limit. The Shakopee Aquifer groundwater influent had an initial PFOA concentration of 320 ng/L, well above the HBV limit (Figure H.25). PFOA was first detected at a specific throughput of 25,798 L/kg in the F400 GAC effluent and 81,342 L/kg in the PFA IX resin.

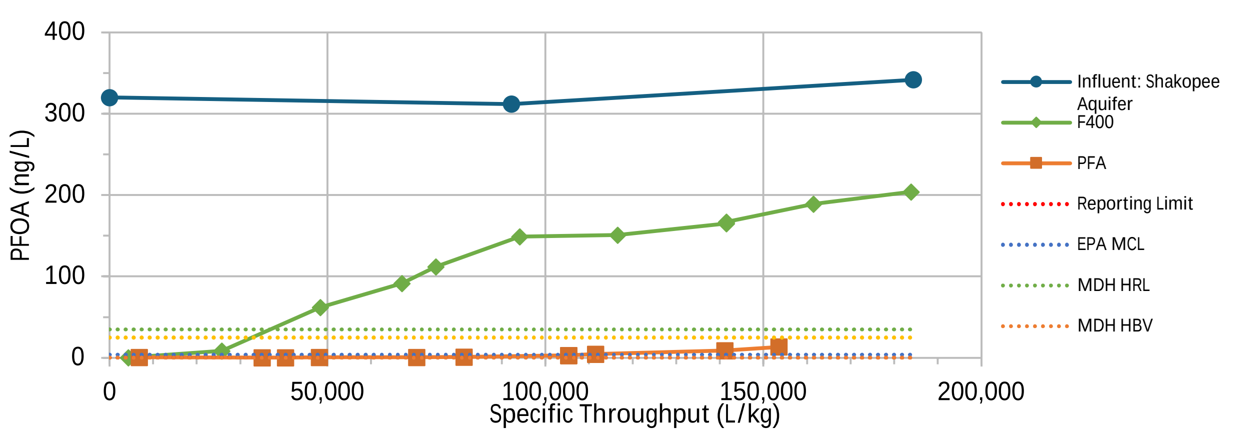

Figure H.25: PFOA Concentrations for Shakopee Aquifer Effluent Samples.

PFHxS (Figure H.26) and PFOS (Figure H.27) exceeded regulatory limits in the F400 GAC column effluent, though F400 was successful in keeping concentrations below influent levels. The PFA column performed better in adsorption of these compounds, as no breakthrough of either compound was observed in the effluent during the test.

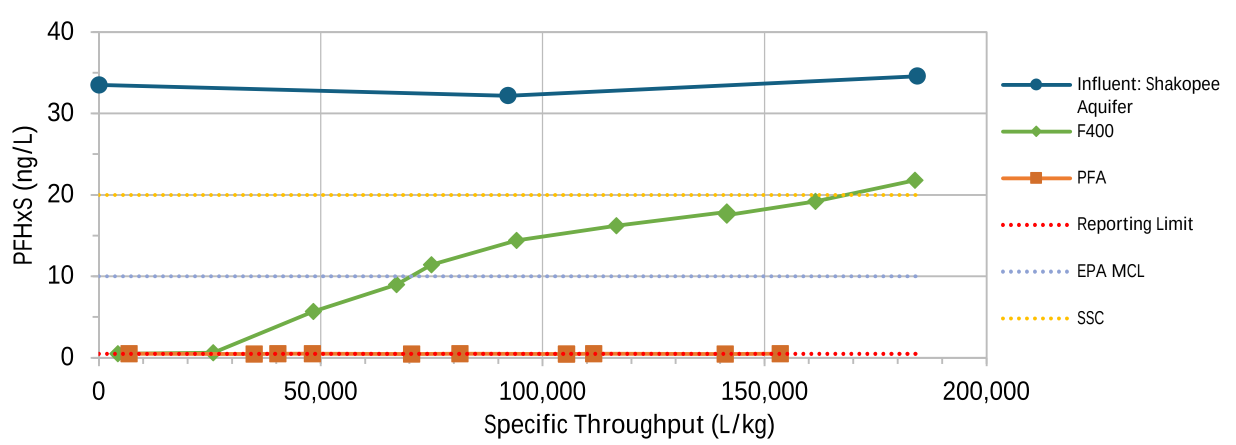

Figure H.26: PFHxS Concentrations for Shakopee Aquifer Effluent Samples.

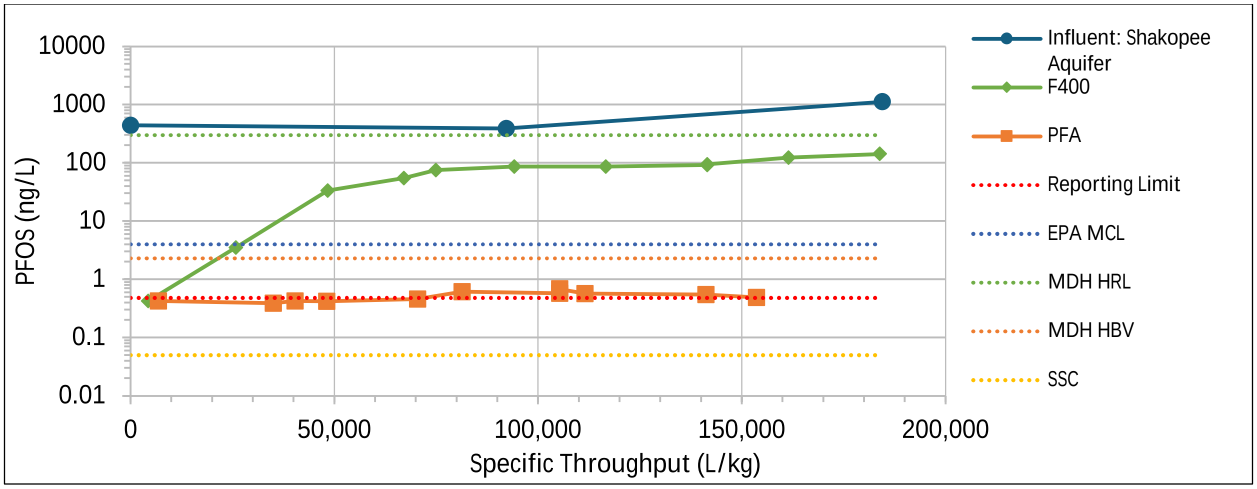

Figure H.27: PFOS Concentrations for Shakopee Aquifer Effluent Samples.

H4.2.2.5 Specific Throughputs at Breakthrough

The breakthrough of a regulated PFAS compound was determined to be when the concentration of the compound in the effluent exceeded the selected treatment criteria regulatory limit. A summary of the specific throughput at which each column reached breakthrough for a compound is shown in Table H.15.

Table H.15: Summary of Specific Throughputs at Breakthrough for Shakopee Aquifer.

Criterion	Units	F400 GAC	PFA IX Resin
Based on MDH HBV PFOA = 0.2 ng/L	L/kg	25,798	81,342
Based on MDH HBV PFOS = 2.3 ng/L	L/kg	22,000	>153,569
Based on EPA MCL PFHxS = 10 ng/L	L/kg	71,000	>153,569
Based on MDH HRL PFBA = 7000 ng/L	L/kg	>183,882	>153,569
Based on MDH HRL PFHxA = 200 ng/L	L/kg	>183,882	>153,569
Based on MDH HRL PFBS = 100 ng/L	L/kg	>183,882	>153,569
Based on MCL HI = 1.0	L/kg	57,000	>153,569
Based on Thyroid HRI = 1.0	L/kg	48,358	>153.569
Minimum Specific Throughput	L/kg	22,000	81,342
MTZ	cm	NA (1)	NA (1)
MTZ Relative	%	NA	NA

(1) MTZ could not be calculated for either GAC or IX media as treated effluent concentrations of PFOA, PFOS, and PFHxS never reached influent (untreated levels).

All regulated compounds, except for those not present above limits in the Shakopee Aquifer groundwater, achieved breakthrough in the F400 GAC column effluent during the test. In contrast, only one compound (PFOA) was detected in the PFA IX resin column effluent above the regulatory threshold. The PFA IX resin outperformed the F400 GAC column at PFOA removal, with a first detection at 81,342 L/kg specific throughput. PFOA first broke through the F400 column earlier at 25,798 L/kg. One kg of the PFA IX resin is estimated to treat a minimum of 81,342 L of groundwater from the Shakopee Aquifer, compared to 22,000 L of F400 GAC. The PFA IX resin performed better than the F400 GAC at overall adsorption.

H4.2.2.6 Mass Transfer Zone Calculations

MTZ could not be calculated for either the F400 GAC or the PFA IX resin for groundwater from the Shakopee Aquifer. The concentrations of PFOA, PFOS, and PFHxS in the F400 column effluent did not reach the level found in the influent samples. Likewise, the PFA column effluent did not meet influent concentration for PFOA, and PFOS and PFHxS were not observed about laboratory method detection limits.

H4.2.2.7 Other Notable Results

TOC concentrations for the Shakopee Aquifer influent, F400 effluent, and PFA effluent are shown in Figure H.28. TOC remained undetected for all influent and effluent samples (detection limit of 1.0 mg/L).

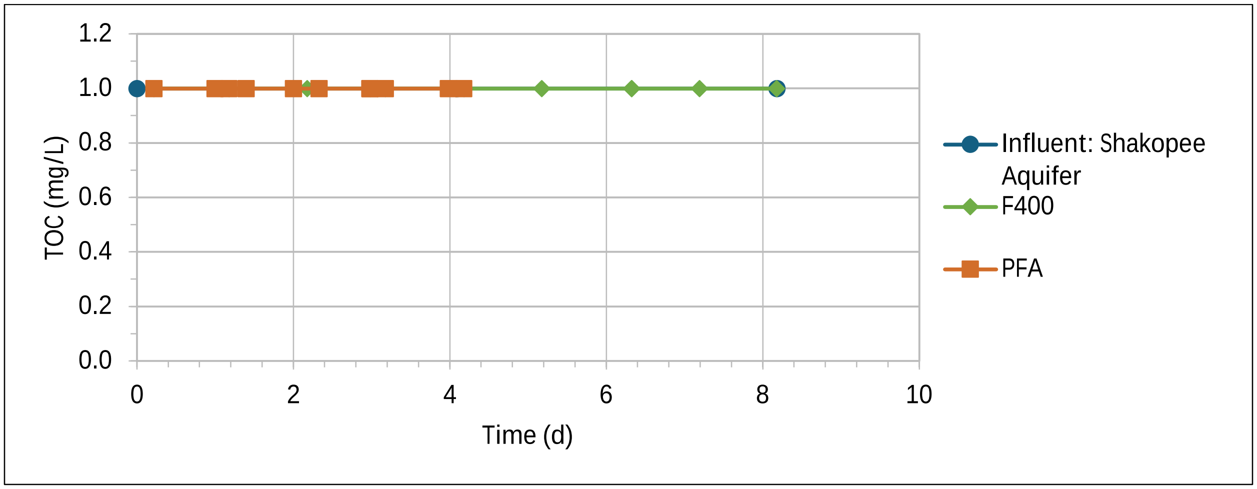

Figure H.28: TOC Concentrations for Shakopee Aquifer Effluent Samples.

Turbidity levels for Shakopee Aquifer influent and effluents were tracked and shown in Figure H.29. The influent turbidity averaged 0.45 NTU throughout the duration of the test. The F400 effluents were lower at approximately 0.1 NTU throughout the test, though a spike to 0.23 NTU on day 7 was observed before dropping back to 0.08 NTU the next day. The PFA column effluents' turbidity was higher than F400, staying at approximately 0.25 NTU for the whole test.

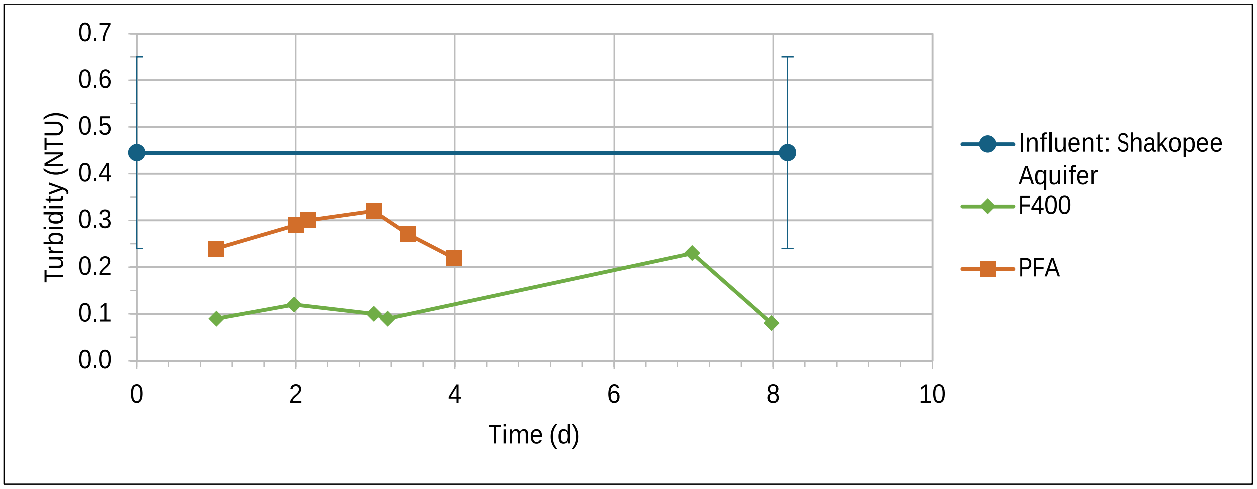

Figure H.29: Turbidity Results for Shakopee Aquifer Effluent Samples.

Flowrates and probe measurements (ORP, pH, and EC) for Shakopee Aquifer samples are shown in Figure H.30. Flowrates for both PFA and F400 columns stayed near the target of 2.5 mL/min for the duration of the test. F400 and PFA ORP readings stayed similar to the Shakopee Aquifer influent's average of 434 mV throughout the test. The influent's pH values averaged to 8.03. The pH readings for PFA's effluent initially started at 7.45, dropping to 7.43 before increasing to overtime to 8.4. The pH for F400's effluents started higher than the influents at 8.11 and had an overall increasing trend towards 8.53. The Shakopee Aquifer influent had an average of 820.25 µS/cm. The EC readings for F400 stayed around 820 µS/cm throughout the test, spiking at day 7 to 1021 µS/cm, but returned to 824.7 µS/cm for the final day. PFA's EC fluctuated between 787.3 µS/cm to 1289 µS/cm throughout the test.

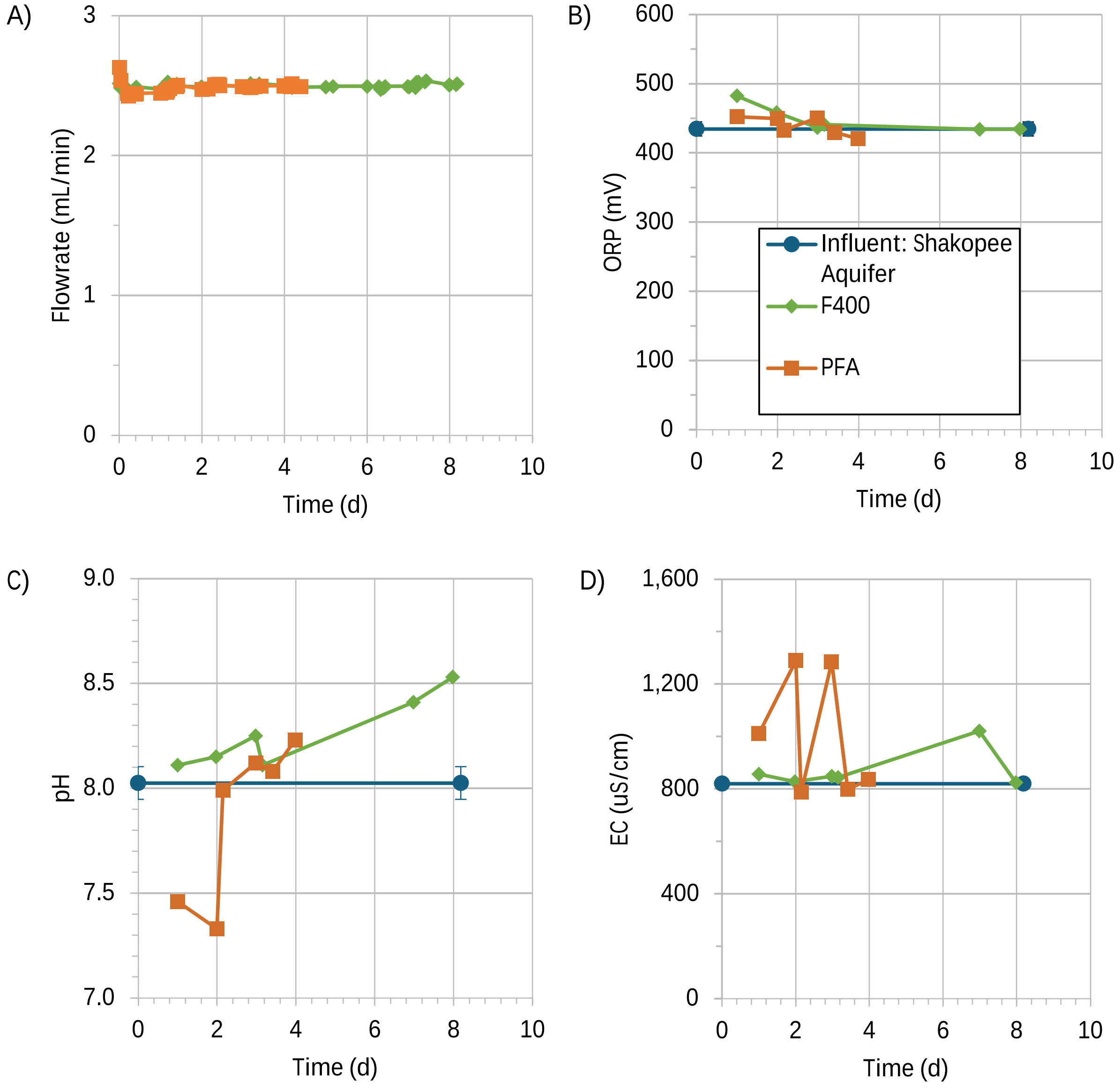

Figure H.30: A) Flowrate, B) ORP, C) pH, and D) EC Results for Shakopee Aquifer Effluent Samples.

Water chemistry results for inorganic constituents including alkalinity, hardness, anions, total and dissolved metals, total suspended and dissolved solids for Shakopee Aquifer samples are presented in Table H.16. Alkalinity and total hardness concentrations remained relatively unchanged between influents and effluent samples. Anions such as chloride, nitrate, sulfate, and calcium also saw little change in concentration between the influents and effluent samples for both columns. Total and dissolved iron was undetected for all samples. Total and dissolved calcium and magnesium concentrations also remain unchanged from the influents through the final effluent samples for both columns. Total manganese remained undetected for the F400 column and initial and final influent samples but saw concentrations of 0.68 µg/L for the middle influent sample and 1.2 µg/L for the final PFA effluent sample. A similar trend was observed for the dissolved manganese concentration, with the middle influent sample having a concentration of 0.73 µg/L and the final PFA sample having 1.2 µg/L concentration. TSS concentration for the influent was 0.66 mg/L for the initial sampling and undetected for the middle sampling event. The final F400 effluent had 0.99 mg/L TSS while the PFA's final effluent had TSS of 2.01 mg/L. TDS remained relatively similar for all sampled influent and effluent events. TSS and TDS results for the final influent sampling event were not tested due to insufficient sample remaining.

Table H.16: General Water Chemistry and Metals Concentrations for Shakopee Aquifer.

Parameter	Units	Influent Samples			F400 Effluent		PFA Effluent	
		Initial	Middle	Final	Initial	Final	Initial	Final
Alkalinity, Total as $CaCO_3$	mg/L	220	216.5	212	218	221	218	217
Total Hardness	mg/L	291	291	309	308	297	297	306
Chloride	mg/L	138	135.5	133	-	134	-	137
Nitrate as Nitrogen	mg/L	2.4	2.4	2.3	-	2.3	-	2.4
Sulfate	mg/L	12.9	13.1	13	-	12.6	-	13
Calcium	mg/L	78.5	77.6	83.4	-	79.4	-	78.3
Iron	µg/L	<50	<50	<50	-	<50	-	<50
Magnesium	mg/L	24.4	23.7	24.5	-	24.0	-	23.5
Manganese	µg/L	<0.5	0.68	<0.5	-	<0.5	-	1.2
Calcium, Dissolved	mg/L	83.5	78.8	82.6	-	84.5	-	84.1
Iron, Dissolved	µg/L	<50	<50	<50	-	<50	-	<50
Magnesium, Dissolved	mg/L	25.3	24.1	23.9	-	23.8	-	24.1
Manganese, Dissolved	µg/L	<0.5	0.73	<0.5	-	<0.5	-	1.2
TSS	mg/L	0.66	<0.057	-	-	0.99	-	2.01
TDS	mg/L	444	475	-	-	458	-	466

H4.2.3 Washington County Landfill Groundwater Results

H4.2.3.1 Total PFAS Results

Total PFAS concentration was calculated for WCL influent and column effluent samples and are given in Figure H.31. Both the F400 GAC column and the PFA IX resin column effluent Total PFAS concentrations reached influent concentrations early in the test duration. This is likely due to the high concentration of PFAS in WCL water, which is much higher than any of the other tested water sources. High levels of PFAS are expected to exhaust the sorbent columns more quickly.

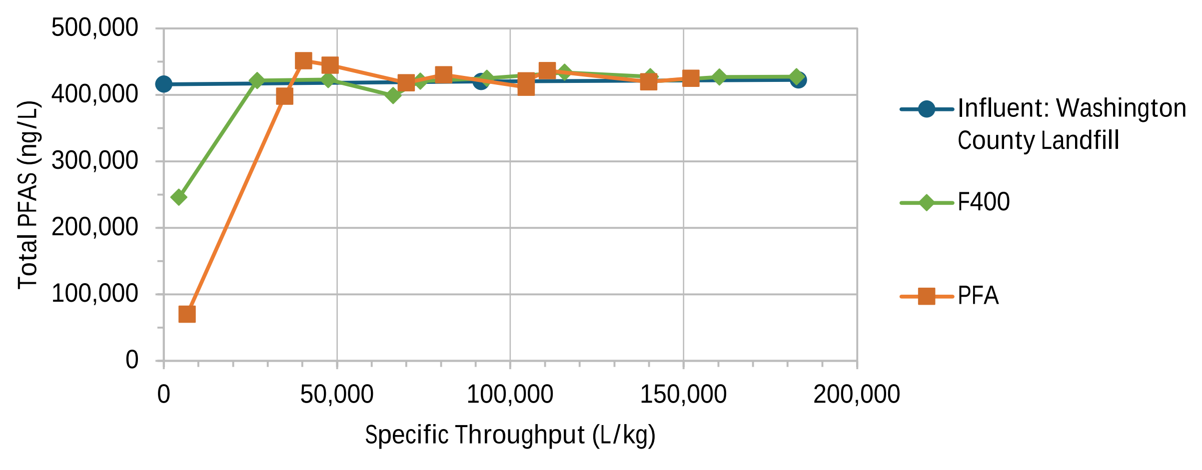

Figure H.31: Total PFAS Concentrations for WCL Effluent Samples.

H4.2.3.2 Hazard Index Results

WCL influent had the highest HI concentration of the water sources tested. The initial influent concentration HI was 77.6, greatly exceeding the regulatory limit of 1.0 (Figure H.32). Both sorbents tested on this water had effluents that exceeded the HI limit of 1 on their first collected sample. At a specific throughput of 4,391 L/kg, the F400 HI was 65.5 and at a specific throughput of 6,723 L/kg, the PFA HI was 1.96. This indicates the actual specific throughout at the time of the HI exceeding 1 would be lower for both the F400 and the PFA, with the F400 expected to be significantly lower than the measured 4,391 L/kg. F400 quickly equaled the influent HI (at approximately 45,000 L/kg) while PFA plateaued at a HI of approximately 65, though it reached this HI at approximately 35,000 L/kg.

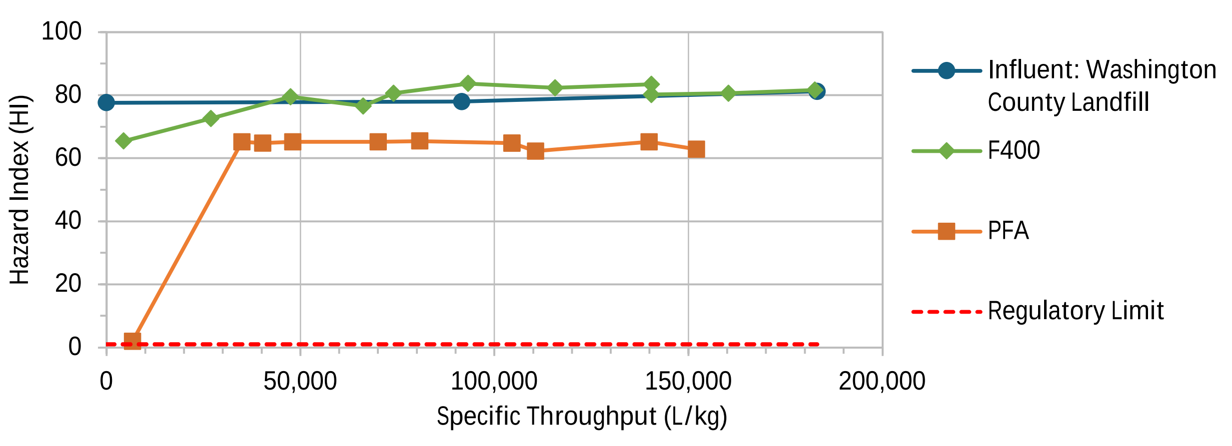

Figure H.32: Hazard Index of Regulated PFAS Concentrations for WCL Effluent Samples.

H4.2.3.3 Thyroid Health Rish Index Results

The thyroid HRI had the highest influent concentration for WCL surface water with an average of 146, two orders of magnitude higher than the regulatory limit of 1.0 (Figure H.33). Both sorbents, PFA and F400, were above the threshold on the first sample at 6,723 L/kg and 4,391 L/kg specific throughputs, respectively. The PFA initial thyroid HRI was 10.3 and reached saturation by the end of the test. In addition, F400’s initial thyroid HRI was 47.5 and was saturated at a specific throughput of 47,478 L/kg.

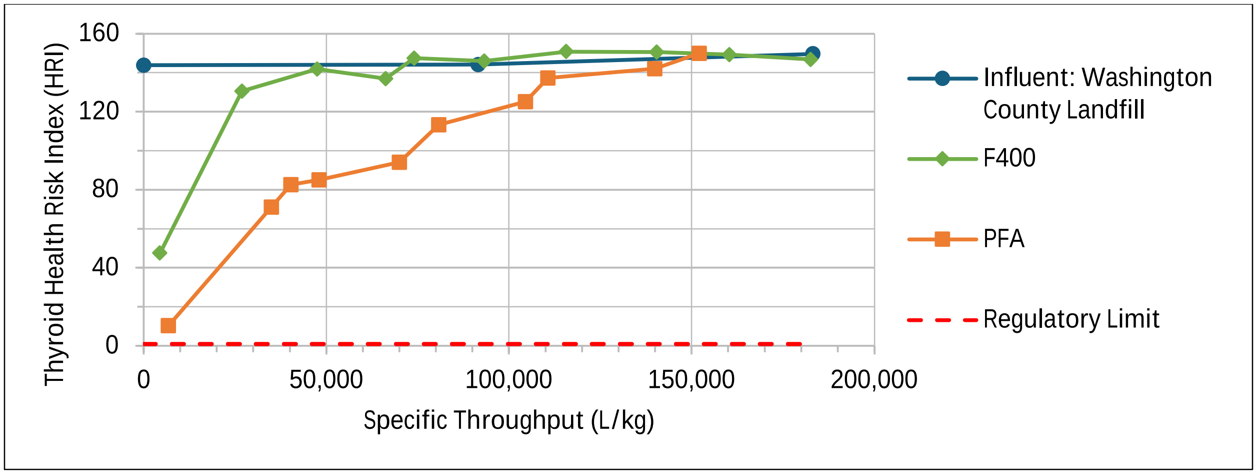

Figure H.33: Thyroid Health Risk Index for WCL Effluent Samples.

H4.2.3.4 Regulated PFAS Compounds

PFAS compounds that are regulated by the EPA and MDH were monitored in effluent samples and compared to the selected treatment criteria. Due to the higher PFAS concentrations in WCL groundwater, the samples analyzed for PFAS had to be diluted more than other samples tested. Therefore, the reporting limits from the analytical laboratory were higher than those achieved for samples from the other water sources. The exception to this, however, is the initial sample for the PFA column effluent, where method reporting limits were one to two orders of magnitude lower than reporting limits for the other effluent samples. As a result, some PFA figures appear to have a large increase in effluent concentration between the first and second samples, but this is an artifact of the change in detection limits. For PFOA, PFOS, PFHxS, and PFBA, the reporting limit was higher than the regulatory threshold for each compound. In these cases, the first detection of the compound in a column's effluent was used as the point in which the regulatory limit was exceeded.

For the regulated compounds PFBA (Figure H.34), PFHxA (Figure H.35), and PFOA (Figure H.36), both the F400 GAC and PFA IX resin columns rapidly saw concentrations above the regulatory limit in the effluent. The concentrations of these compounds generally reached the influent levels before the end of the test, with the exception of PFOA in the PFA column, where PFOA concentration reached approximately 60% of the influent concentration by the end of the test. Note that though the effluent concentration of PFA did not reach the influent concentration, the final PFOA concentration in the PFOA column (7,600 ng/L) was well above regulatory limits.

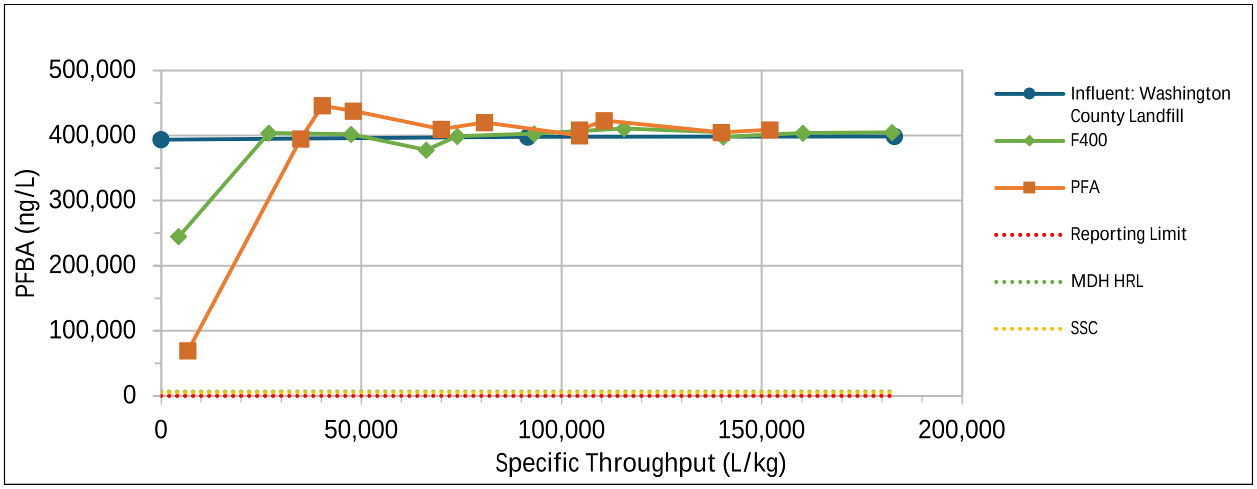

Figure H.34: PFBA Concentrations for WCL Effluent Samples.

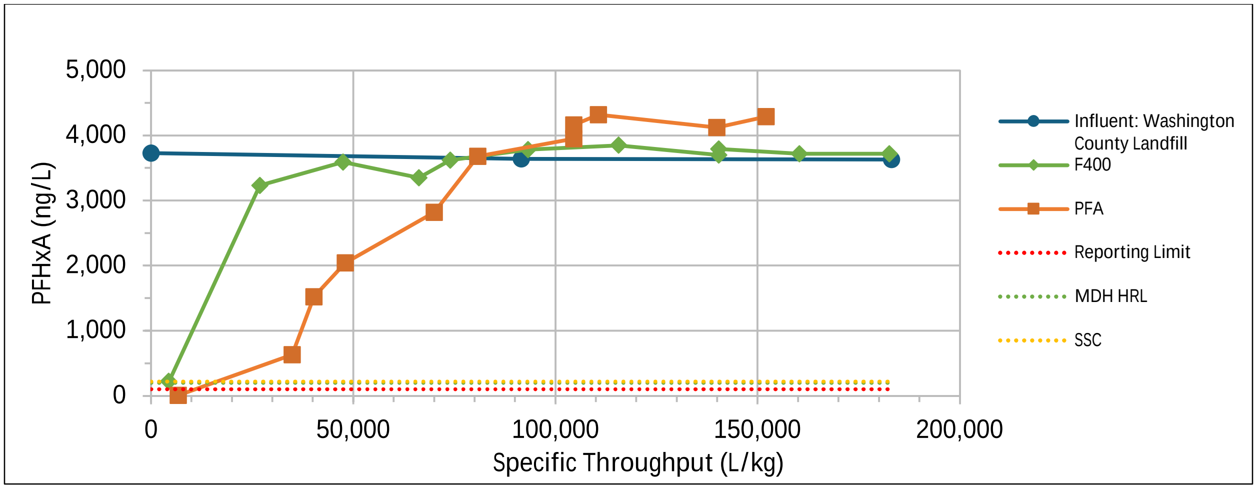

Figure H.35: PFHxA Concentrations for WCL Effluent Samples.

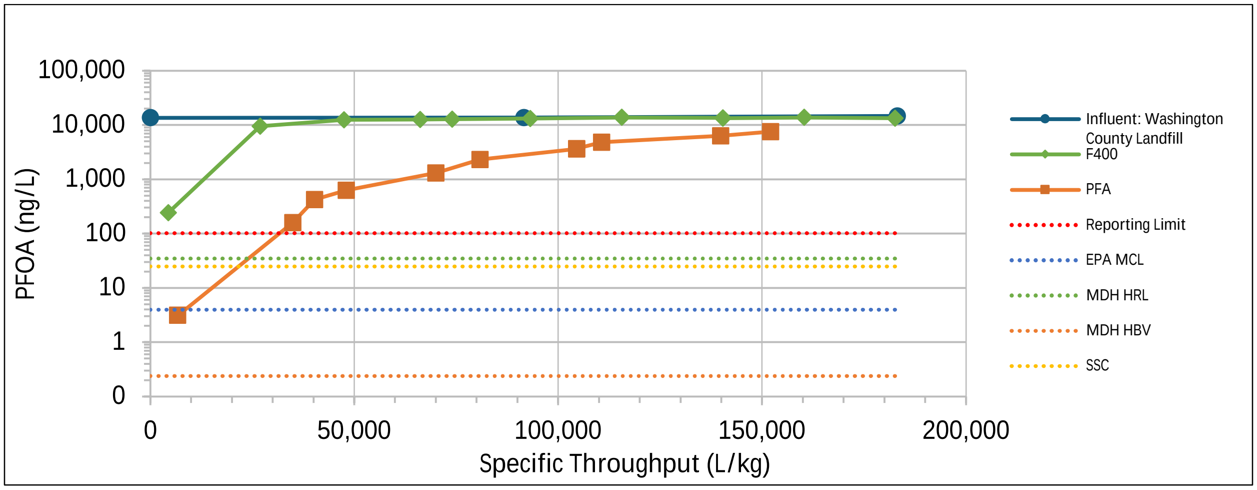

Figure H.36: PFOA Concentrations for WCL Effluent Samples.

In contrast, PFBS (Figure H.37), PFHxS (Figure H.38), and PFOS (Figure H.39) were treated to below the elevated method reporting limit in the PFA column effluent. However, as previously discussed, the reporting limit after the first effluent sample was elevated, so it is unknown if these compounds broke through the column above applicable regulatory limits. In contrast, PFBS, PFHxS, and PFOS were observed to have broken through in the F400 column effluent, reached the influent concentration for both PFBS and PFHxS, and approached the influent concentration for PFOS.

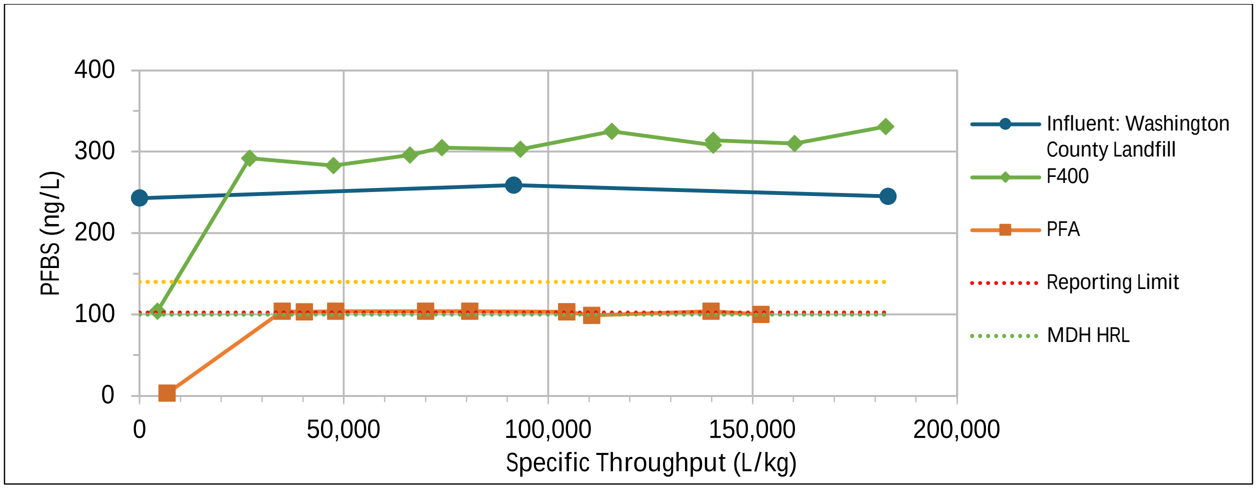

Figure H.37: PFBS Concentrations for WCL Effluent Samples.

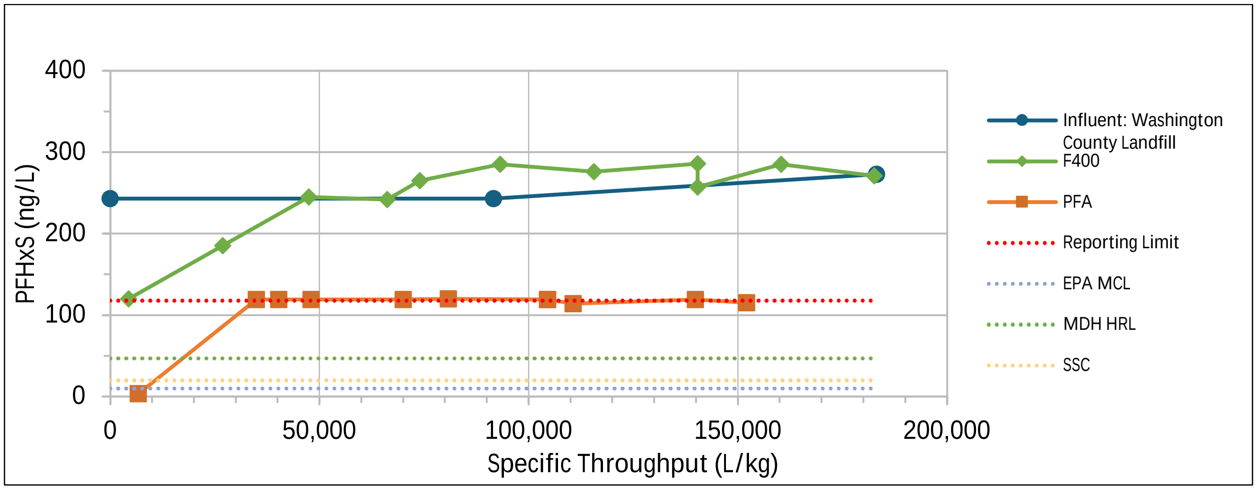

Figure H.38: PFHxS Concentrations for WCL Effluent Samples.

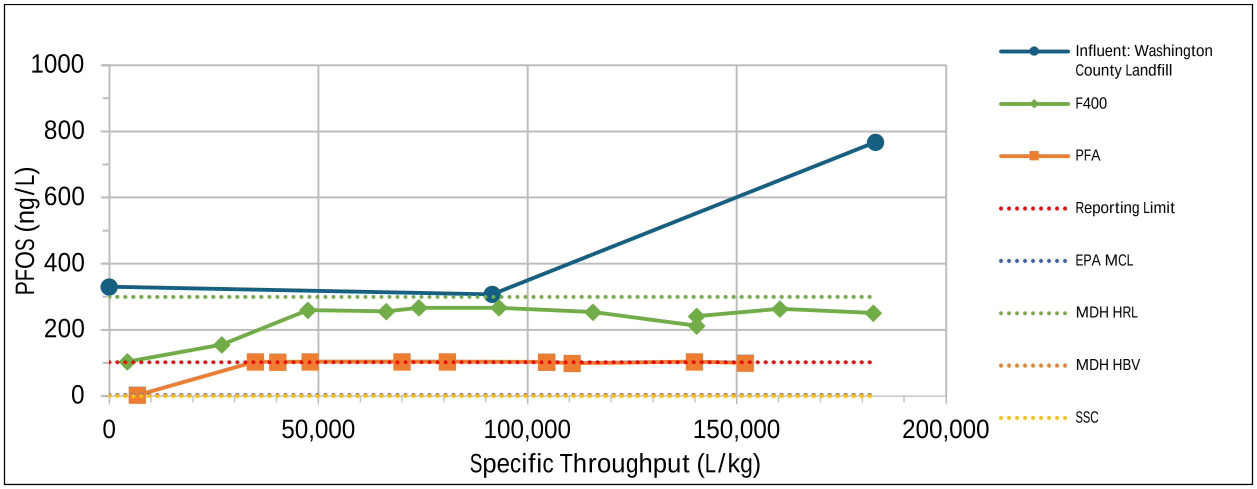

Figure H.39: PFOS Concentrations for WCL Effluent Samples.

H4.2.3.5 Specific Throughputs at Breakthrough

The breakthrough of a regulated PFAS compound was determined to be when the concentration of the compound in the effluent exceeded the selected treatment criteria regulatory limit. A summary of the specific throughput at which each column reached breakthrough for a compound is shown in Table H.17. Note that for some compounds, the first sample exceeded or greatly exceeded regulatory limits, thus the actual specific throughput would be less than the specific throughput at which the sample was collected.

Table H.17: Summary of Specific Throughputs at Breakthrough for WCL Groundwater.

Criterion	Units	F400 GAC	PFA IX Resin
Based on SSC PFOA = 25 ng/L	L/kg	< 4,391	21,000
Based on SSC PFOS = 0.05 ng/L	L/kg	< 4,391	> 152,072
Based on SSC PFHxS = 20 ng/L	L/kg	< 4,391	> 152,072
Based on SSC PFBA = 5700 ng/L	L/kg	< 4,391	< 6,723
Based on SSC PFHxA = 220 ng/L	L/kg	< 4,391	17,000
Based on SSC PFBS = 140 ng/L	L/kg	9,000	> 152,072
Based on EPA MCL HI = 1.0	L/kg	< 4,391	< 6,723
Based on Thyroid HRI = 1.0	L/kg	< 4,391	< 6,723
Minimum Specific Throughput	L/kg	< 4,391	< 6,723
MTZ (based on PFBA)	cm	0.26	0.71
MTZ Relative	%	15%	75%

Both sorbents showed quicker breakthrough when compared to the other tested water sources. This is unsurprising, due to the higher concentrations found in WCL groundwater, which is more likely to exhaust the sorbent columns. Similar to the other groundwaters tested, the PFA IX resin column outperformed the F400 GAC column, as it kept PFOS, PFHxS, and PFBS concentrations below method reporting limits for the duration of the test. The PFA IX resin column was more effective at removing these sulfonic acid PFAS than their respective carboxylic acid PFAS: PFOA, PFHxA, and PFBA. However, this is likely due in large part to the initial concentrations of PFOA, PFHxA, and PFBA being 1 to 3 orders of magnitude higher than the corresponding sulfonic acid PFAS.

H4.2.3.6 Mass Transfer Zone Calculations

The MTZ was calculated using PFBA for both the F400 and PFA columns. PFBA was the first compound to achieve breakthrough from the PFA IX resin column. The MTZ for PFA was 0.71 cm, or 75% of the entire bed depth, and 0.26 cm, or 15% of the bed depth for F400 (Table H.17). Although the PFA performed better at PFAS adsorption, the F400 had a smaller MTZ. PFBA broke through first in the F400 effluent in terms of specific throughput, but it took longer to break through in terms of days of runtime.

H4.2.3.7 Other Notable Results

TOC concentrations for WCL influent and treated effluent samples are shown in Figure H.40. Influent concentrations remained consistent between 5.2 mg/L and 5.4 mg/L throughout the test. The F400 column initially showed greater TOC with an effluent TOC concentration of 2.5 mg/L after the first sampling event, but the TOC concentrations increased to approximately 5.0 mg/L after the third sampling event and stabilized there until the end of the test. The PFA column showed similar trends, though initial removal was lower (first effluent sample was 3.5 mg/L), with increasing and stabilizing at 5.0 mg/L.

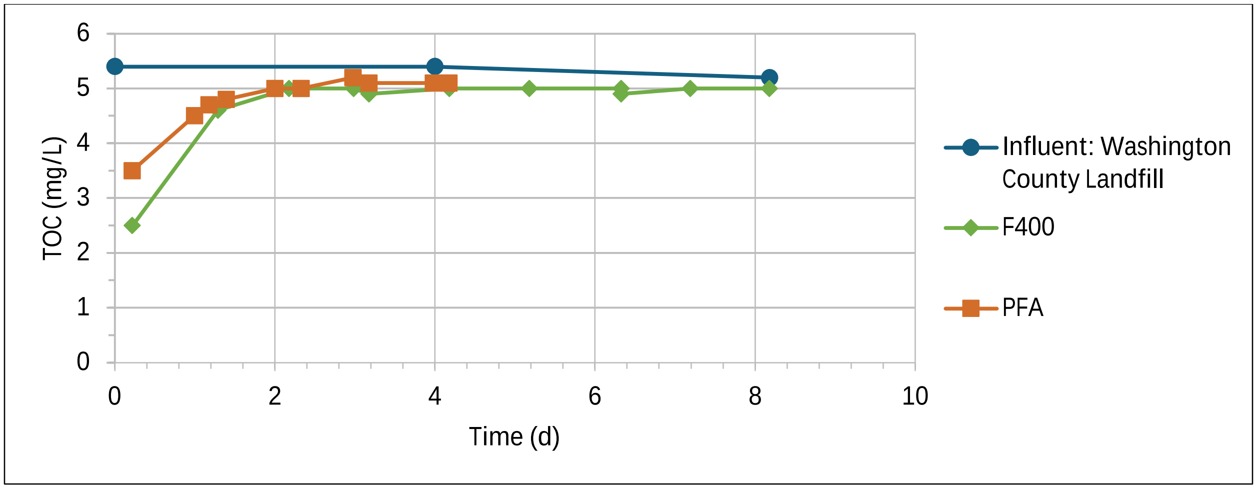

Figure H.40: TOC Concentrations for WCL Effluent Samples.

Turbidity readings for WCL are shown in Figure H.41. WCL influent had an average of 0.46 NTU throughout the test. The turbidity from the F400 effluents initially had a downward trend for the first four sampling events, from 0.36 NTU to 0.23 NTU, though it increased afterwards, with a maximum reading of 0.55 NTU before decreasing to 0.46 NTU for the final sample. PFA turbidity had an overall downwards trend, initially starting at 0.6 NTU and eventually reaching 0.22 NTU.

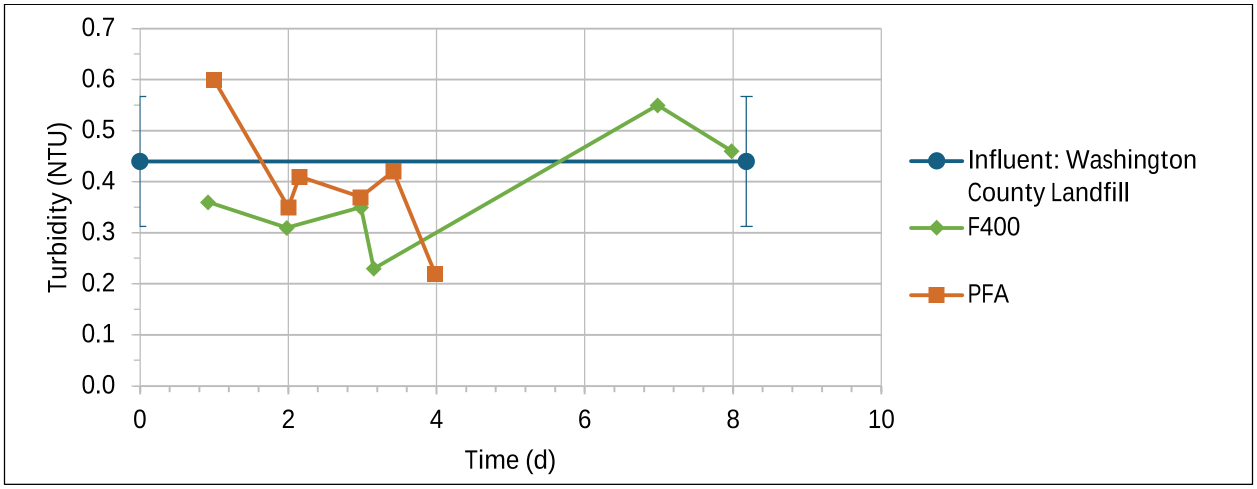

Figure H.41: Turbidity Results for WCL Effluent Samples.

Water quality and operational parameters including flowrate, ORP, pH, and EC trends were tracked for WCL influent and effluent samples (Figure H.42). The flowrates for both columns stayed within 10% of the target flow for the entire duration of the test. The influent ORP averaged 355 mV, and the F400 effluent initial reading was similar at 367 mV. F400's ORP gradually increased to 409 mV and stabilized there until the end of the test. The PFA column's ORP initially started at 442 mV before quickly dropping to 336 mV. It then increased to 390 mV and stabilized there for the remainder of the test. pH for WCL influent and effluent samples remained mostly neutral between 7.36 – 7.91. EC for WCL influent averaged 1,150 µS/cm. The PFA's effluents saw a decreasing trend in EC from 1,720 µS/cm to 816 µS/cm. F400's EC stayed mostly stable around 1,040 µS/cm.

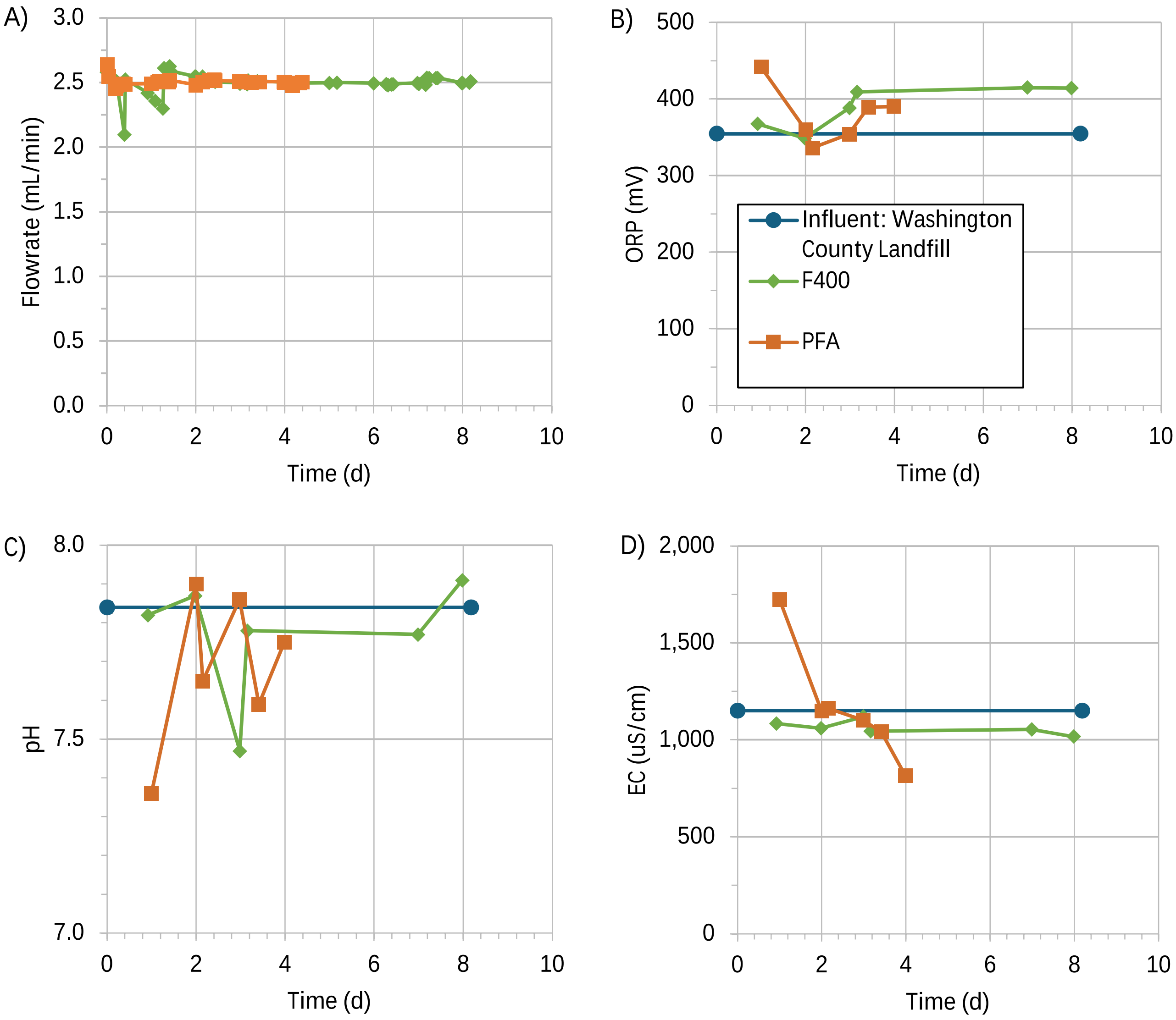

Figure H.42: A) Flowrate, B) ORP, C) pH, and D) EC Results for WCL Effluent Samples.

Water chemistry results for inorganic constituents including alkalinity, hardness, anions, total and dissolved metals, total suspended and dissolved solids for WCL's samples are given in Table H.18. The alkalinity concentration in the influent samples decreased as the test went on, with an initial concentration at 515 mg/L and the final concentration at 268 mg/L. The F400 effluent also saw a decrease in alkalinity between the initial (500 mg/L) and final (386 mg/L) concentrations. The alkalinity concentration in the PFA effluent increased slightly between the initial (508 mg/L) and final (579 mg/L) samples.

A similar trend was observed in the total hardness of the influent and effluent samples. The anions (chloride, nitrate, sulfate) concentrations saw no meaningful change between influent and effluent samples. The total and dissolved calcium influent concentration decreased over the course of the test. Both the F400 and PFA final effluent total and dissolved calcium concentrations were lower than the initial and middle influent concentrations but higher than the final influent concentrations. Iron was undetected for all samples. Total and dissolved magnesium had little change between the influent and treated effluent samples. Total and dissolved manganese had much lower concentrations for the final influent and F400 effluent sample compared to the initial and middle influent samples. The PFA effluent manganese concentration had a slight decrease from the initial and middle influent samples. TSS was undetected for the influent samples, while F400 had 2.58 mg/L TSS concentration and PFA had 1.57 mg/L TSS concentration. TDS for the influent samples were 685.60 mg/L and 718.00 mg/L. The final TDS F400 concentration was 615.00 mg/L while PFA's was much lower at 326.50 mg/L. Final influent samples for TSS and TDS were not analyzed due to insufficient remaining volume.

Table H.18: General Water Chemistry and Metals Concentrations for WCL Samples.

Parameter	Units	Influent Samples			F400 Effluent		PFA Effluent	
		Initial	Middle	Final	Initial	Final	Initial	Final
Alkalinity, Total as $CaCO_3$	mg/L	515	497	268	500	386	508	579
Total Hardness	mg/L	547	539	331	547	456	544	548
Chloride	mg/L	126	123	120	-	122	-	130
Nitrate as Nitrogen	mg/L	0.46	0.50	0.52	-	0.46	-	0.50
Sulfate	mg/L	7.3	7.3	7.1	-	7.1	-	7.3
Calcium	mg/L	129	124	41.3	-	89.2	-	117
Iron	µg/L	<50	<50	<50	-	<50	-	<50
Magnesium	mg/L	56.2	55.9	55.2	-	56.7	-	57.8
Manganese	µg/L	1,440	1,165	123	-	163	-	953
Calcium, Dissolved	mg/L	134	116	35.1	-	92.1	-	114
Iron, Dissolved	µg/L	<50	<50	<50	-	<50	-	<50
Magnesium, Dissolved	mg/L	57.9	53.8	54.2	-	57.0	-	58.0
Manganese, Dissolved	µg/L	1,430	1,125	11.3	-	169	-	665
TSS	mg/L	< 0.057	< 0.057	-	-	2.58	-	1.57
TDS	mg/L	685	718	-	-	615	-	327

H4.2.4 SAFF® Treated Shakopee Aquifer Groundwater Results

H4.2.4.1 Total PFAS Results

Total PFAS concentration was calculated for SAFF® treated Shakopee Aquifer groundwater influent and column effluent samples and are given in Figure H.43. The Total PFAS concentration in the PFA column effluent was lower than that of both the F400 GAC column and the influent for the duration of the test. PFA effluent approached but never reached the influent Total PFAS concentration, while the F400 effluent reached the influent Total PFAS concentration after a specific throughput of approximately 115,000 L/kg. Total PFAS results demonstrate better overall performance of PFA compared to F400, as fewer compounds broke through during the RSSCT.

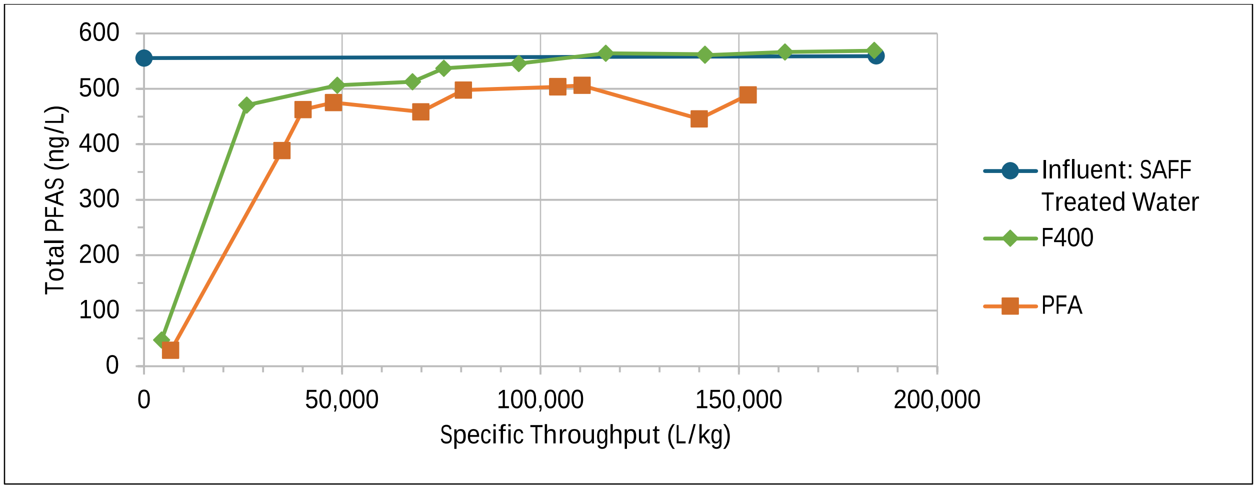

Figure H.43: Total PFAS Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

H4.2.4.2 Hazard Index Results

Due to prior treatment with SAFF®, influent samples had the lowest PFAS concentrations of all groundwater samples tested. The influent did not exceed the HI regulatory limit of 1.0 and had an initial HI of 0.72 (Figure H.44). As the influent did not exceed a HI of 1, likewise all effluent samples were beneath the regulatory HI limit of 1. F400 effluent samples increased throughout the duration of the test, reaching a HI of 0.68 by the end of test. PFA effluent, however, stayed relatively constant throughout the test and did not exceed a HI of 0.27.

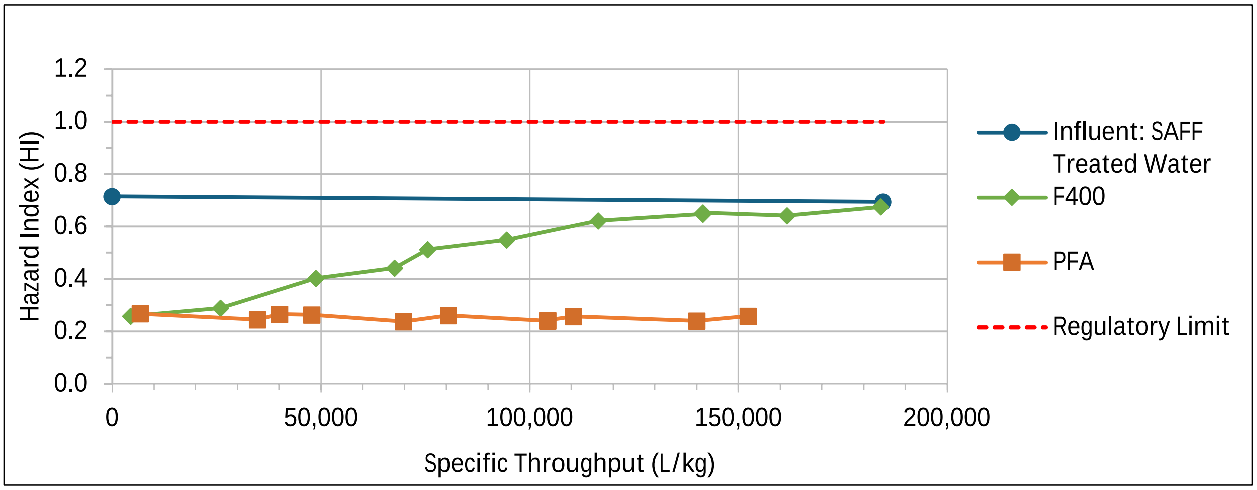

Figure H.44: Hazard Index of Regulated PFAS Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

H4.2.4.3 Thyroid Health Risk Index Results

The Shakopee Aquifer SAFF® treated test water was lower compared to the Shakopee Aquifer test water with an initial thyroid HRI of 1.94, which is above the regulatory limit of 1.0 but below the Shakopee Aquifer initial thyroid HRI 3.5 (Figure H.45). The PFA never reached the threshold with the RSSCT ending at a specific throughput of 152,337 L/kg with a thyroid HRI of 0.35. The F400 GAC surpassed the regulatory limit at an approximate specific throughput of 67,000 L/kg but never reached the inlet concentration with a final thyroid HRI of 1.68 at a specific throughput of 184,093 L/kg.

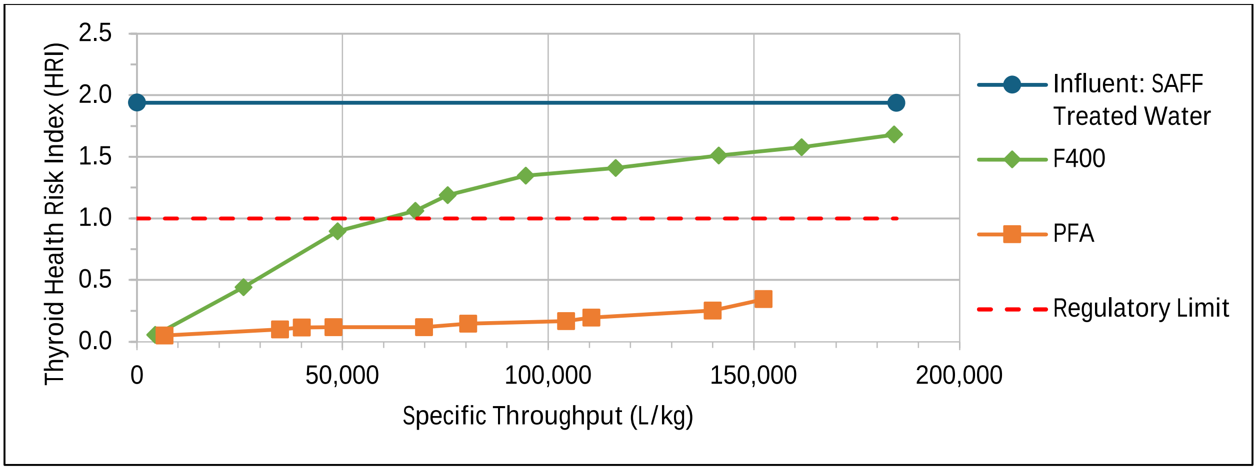

Figure H.45: Thyroid Health Risk Index for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

H4.2.4.4 Regulated PFAS Compounds

PFAS compounds that are regulated by the EPA and MDH were monitored in the effluent and compared to the relevant regulatory limits. In the SAFF® Treated Shakopee Aquifer groundwater, the concentrations of the following compounds did not exceed regulatory limits in the influent: PFBA (Figure H.46), PFHxA (Figure H.47), PFBS (Figure H.48), PFHxS (Figure H.49), and PFOS (Figure H.50). Breakthrough of PFBA was quickly observed for both F400 and PFA, with effluent concentrations from both F400 and PFA reaching the influent concentration by a specific throughput of 40,000 L/kg. However, the influent PFBA concentration of approximately 430 ng/L is well below Minnesota standards and is thus not a driver for media changeout. Similarly, for PFHxS, PFHxA, and PFBS, increases in effluent concentration were observed in F400 effluent samples, with PFBS reaching influent levels and PFHxS and PFHxA effluent concentrations closely approaching influent concentrations. No effluent concentrations exceeded individual compound regulatory limits though. PFA outperformed F400, with no breakthrough of PFBS or PFHxS observed; PFHxA did breakthrough on the PFA test, but at lower concentrations than the F400 test. Influent PFOS concentrations were very low and were "J" qualified data (indicating the data was above the instrument detection limit but below the limit of quantitation/method reporting limit). F400 samples after approximately 116,000 L/kg had "J" qualified results similar to influent concentrations, while no PFA results for PFOS were above the instrument reporting limit.

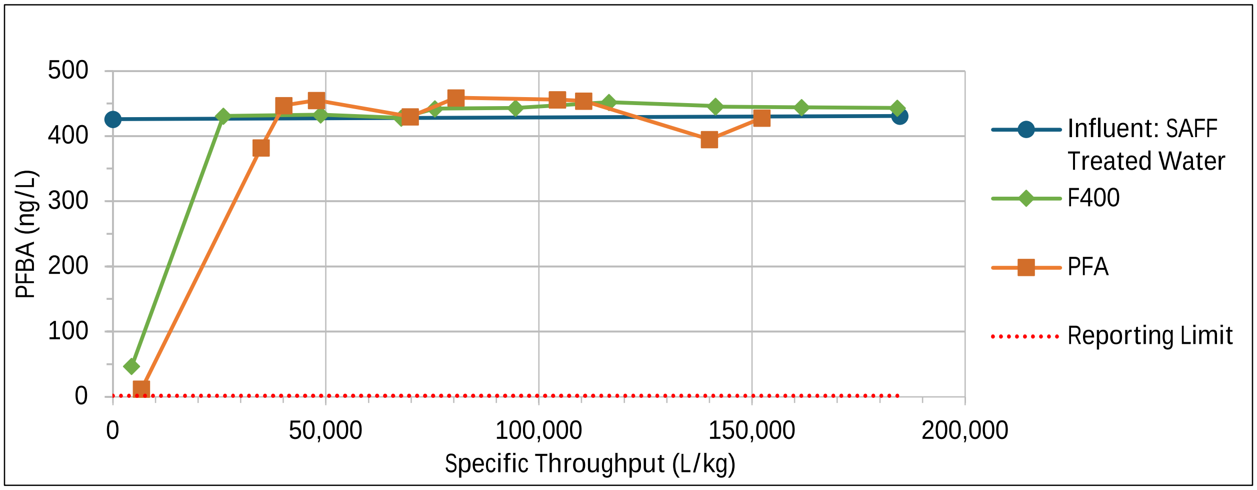

Figure H.46: PFBA Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

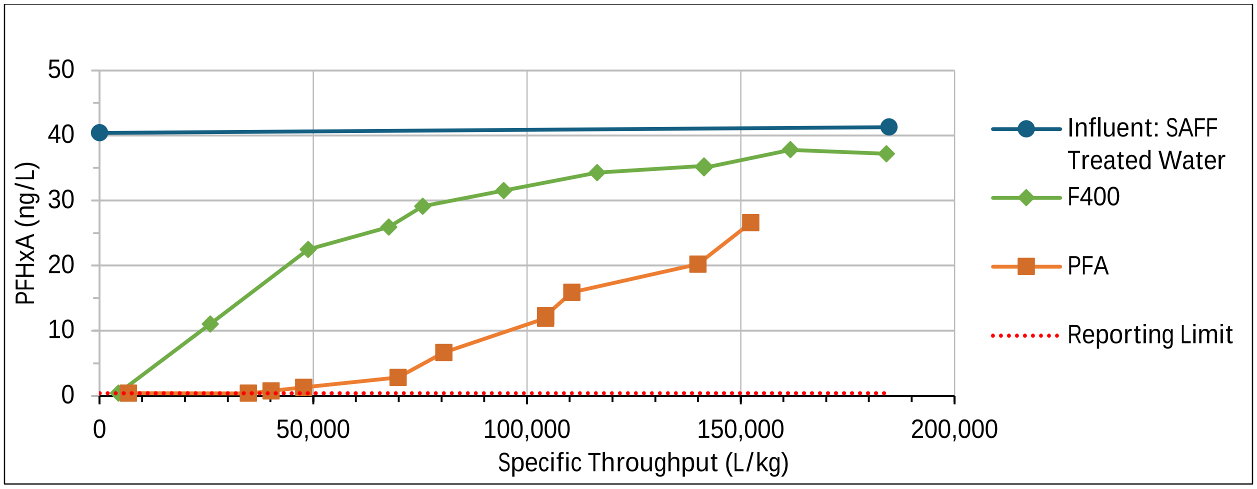

Figure H.47: PFHxA Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

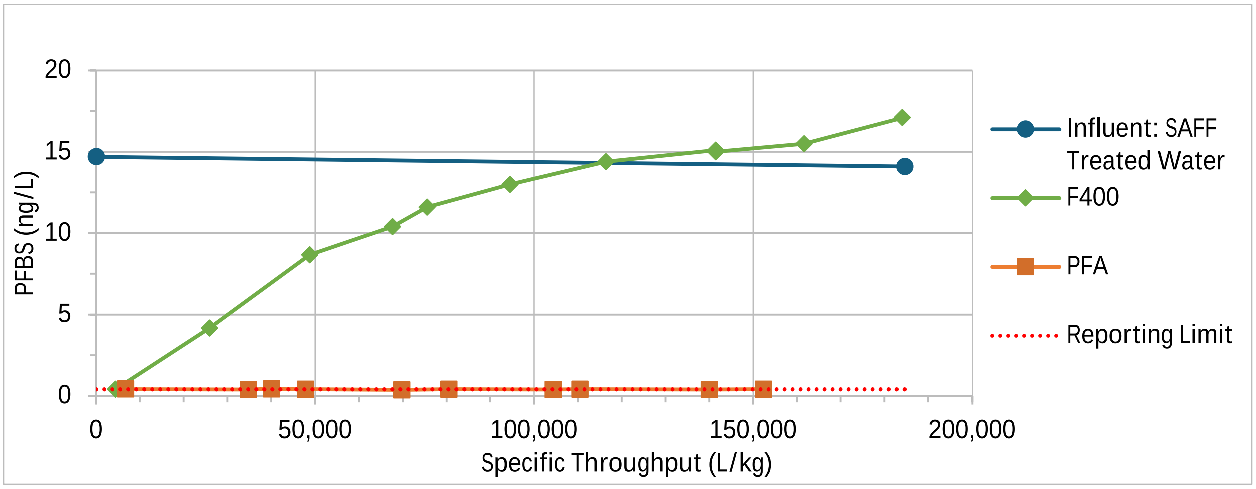

Figure H.48: PFBS Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

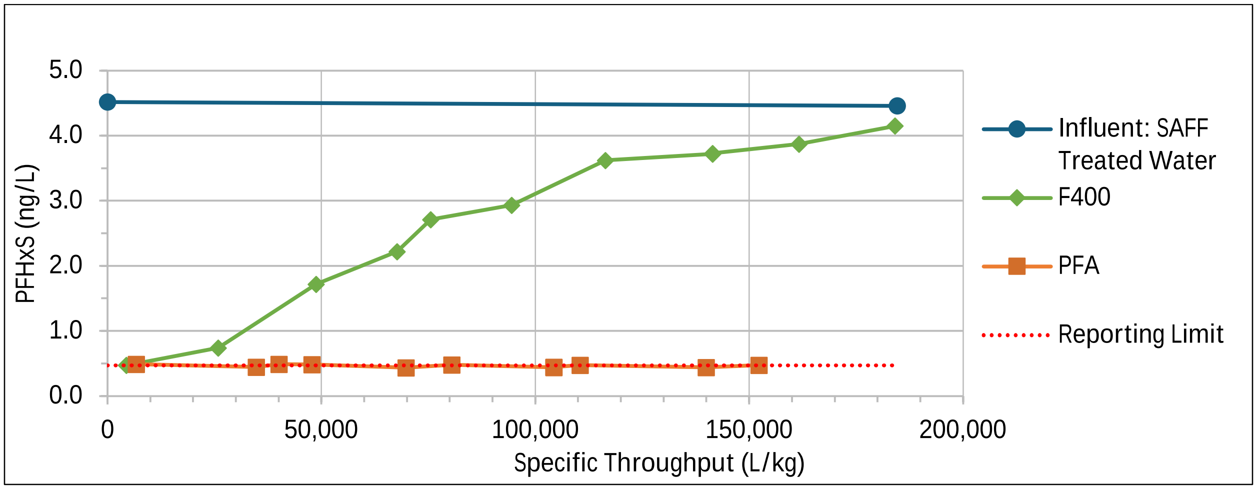

Figure H.49: PFHxS Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

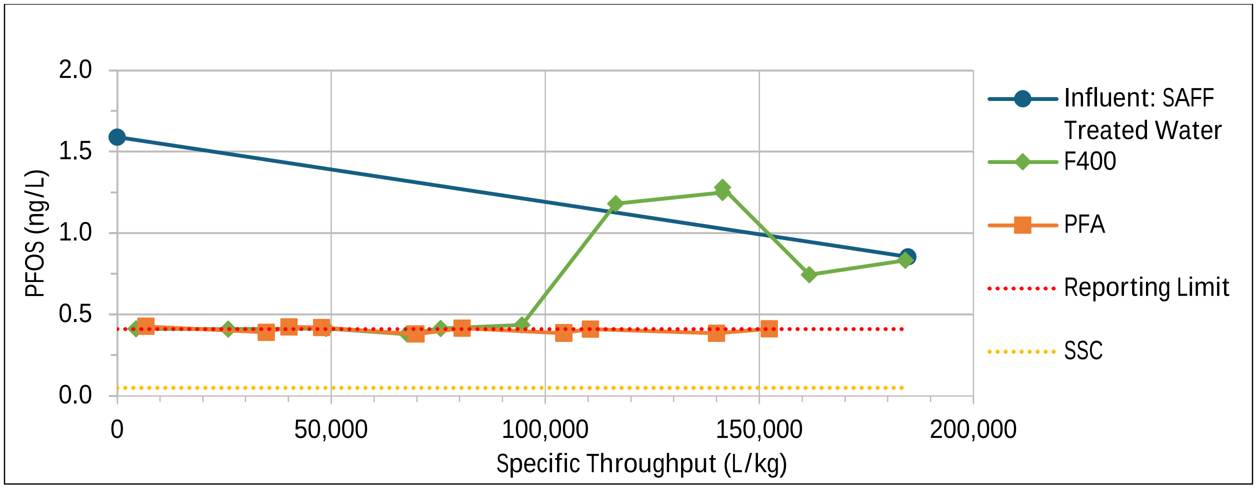

Figure H.50: PFOS Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

The SAFF® Treated Shakopee Aquifer groundwater influent had a PFOA concentration of 12.4 ng/L, which exceeds the MDH HBV value of 0.2 ng/L. PFOA was not detected in the effluent of the PFA column during the duration of the test, therefore also never reaching the regulatory limit. In the F400 test, PFOA was first detected in the effluent at a specific throughput of 25,928 L/kg at a concentration of 2.36 ng/L, exceeding the MDH HBV (Figure H.51).

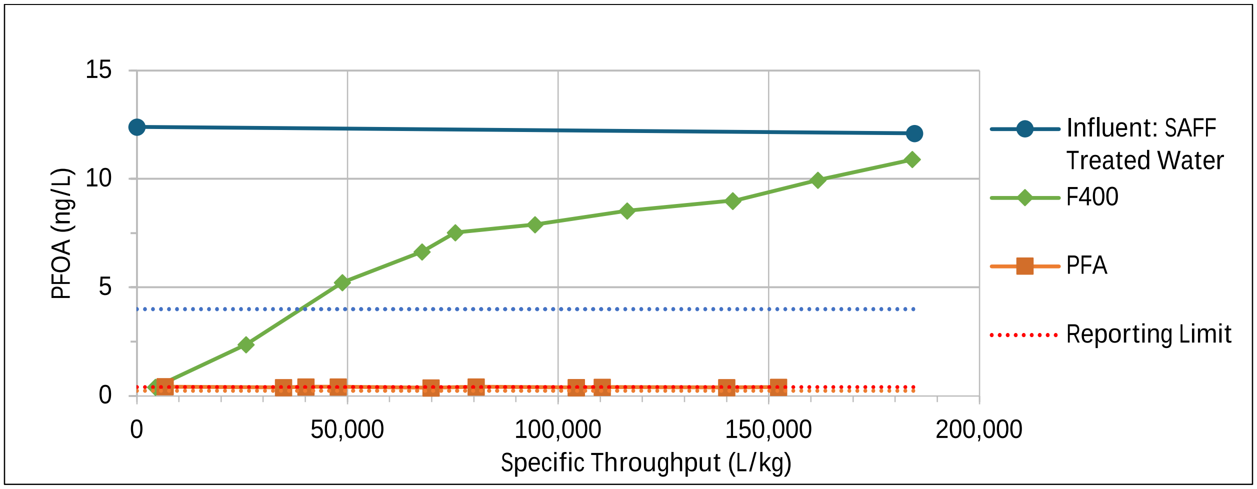

Figure H.51: PFOA Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

H4.2.4.5 Specific Throughputs at Breakthrough

The breakthrough of a regulated PFAS compound was determined to be when the concentration of the compound in the effluent exceeded the selected treatment criteria regulatory limit. A summary of the specific throughput at which each column reached breakthrough for a compound is shown in Table H.19. Only PFOA breakthrough was observed in the F400 test; all other compounds for F400 were below regulatory standards. For PFA, no PFAS effluent concentration exceeded a regulatory standard, and thus no breakthrough was observed.

Table H.19: Summary of Specific Throughputs at Breakthrough for SAFF® Treated Shakopee Aquifer Groundwater.

Criterion	Units	F400 GAC	PFA IX Resin
Based on MDH HBV PFOA = 0.2 ng/L	L/kg	25,928	>152,337
Based on MDH HBV PFOS = 2.3 ng/L	L/kg	>184,093	>152,337
Based on EPA MCL PFHxS = 10 ng/L	L/kg	>184,093	>152,337
Based on MDH HRL PFBA = 7000 ng/L	L/kg	>184,093	>152,337
Based on MDH HRL PFHxA = 200 ng/L	L/kg	>184,093	>152,337
Based on MDH HRL PFBS = 100 ng/L	L/kg	>184,093	>152,337
Based on MCL HI = 1.0	L/kg	>184,093	>152,337
Based on Thyroid HRI = 1.0	L/kg	63,700	>152,337
Minimum Specific Throughput	L/kg	25,928	>152,337

The PFA IX resin was able to keep the PFOA concentration in the column effluent below the MDH HBV for the entirety of the test. This suggests that one kg of the PFA IX resin could be used to successfully treat a minimum of 152,337 L of SAFF® Treated Shakopee Aquifer groundwater using the same conditions as the RSSCT.

PFOA was the only PFAS compound present in the SAFF® Treated groundwater above regulated limits. Therefore, the PFA column performed better than the F400 column, which experienced breakthrough at a specific throughput of 25,928 L/kg.

H4.2.4.6 Mass Transfer Zone Calculations

Calculation of MTZ is focused on PFAS that both exceed their respective regulatory limit and reach an effluent concentration equal to the influent concentration during the test. Only PFBA reached an effluent concentration equal to the influent concentration during the test, but PFBA levels did not exceed regulatory limits. None of the regulated PFAS species reached the initial concentration and exceeded regulatory limits. Thus, MTZ could not be calculated for either the F400 GAC or the PFA IX resin for the SAFF® Treated Shakopee Aquifer groundwater.

H4.2.4.7 Other Notable Results

TOC results for the SAFF® treated water are shown in Figure H.52. Average influent TOC concentration was 1.20 mg/L between the initial and middle sampling events. Final influent TOC concentration was not sampled due to insufficient sample volume. TOC concentrations in the F400 samples were below the detection limit of 1 mg/L until the last sampling event, when TOC was measured at 1.2 mg/L. TOC in PFA samples remained below the detection limit of 1 mg/L for the duration of the test.

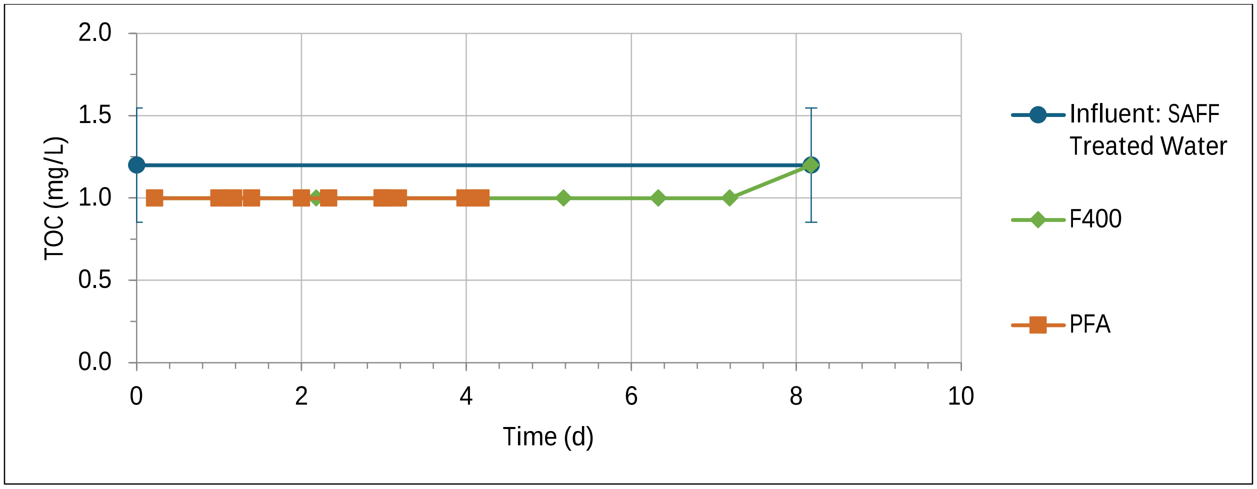

Figure H.52: TOC Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

Turbidity results for the SAFF® treated waters are shown in Figure H.53. Average influent turbidity was 0.36 NTU throughout the test, and F400 samples remained relatively low between 0.10 NTU and 0.14 NTU. PFA turbidity was initially measured at 0.23 NTU before decreasing to approximately 0.1 NTU for the remaining duration of the test.

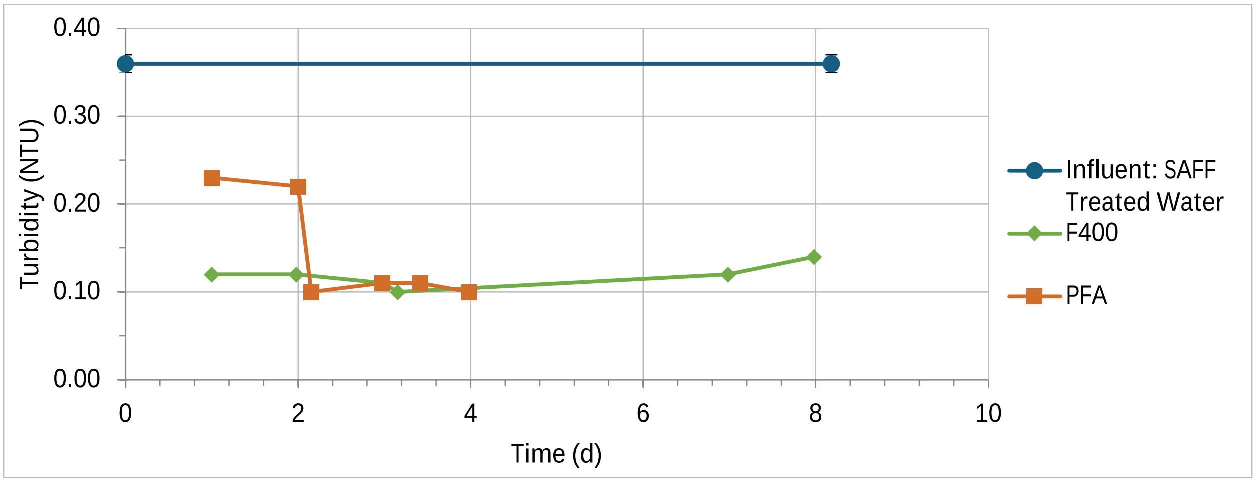

Figure H.53: Turbidity Results for SAFF® Treated Shakopee Aquifer Groundwater Effluent Samples.

Water quality and operational parameters including flowrate, ORP, pH, and EC trends were tracked for SAFF® Treated Shakopee Aquifer groundwater influent and effluent samples (Figure H.54). The flowrates for both columns remained within 10% of target flow for the entire duration of the test. ORP readings for both F400 and PFA effluent samples stayed relatively equal to the influent samples. The pH of the influent averaged 8.30; the PFA pH was initially 7.45 before quickly increasing to 8.33 and stabilizing for the duration of the test. Unlike PFA, there was no initial spike in the F400 effluent pH; instead, the F400 pH was initially 8.32 and gradually increased to 8.48. EC readings for both the influent samples and F400 effluent stayed consistent around 800 µS/cm. The initial PFA EC was measured at 1,100 µS/cm, increased to 1,200 µS/cm, and then dropped down to 800 µS/cm on the third sampling event and remained there for the duration of the test.

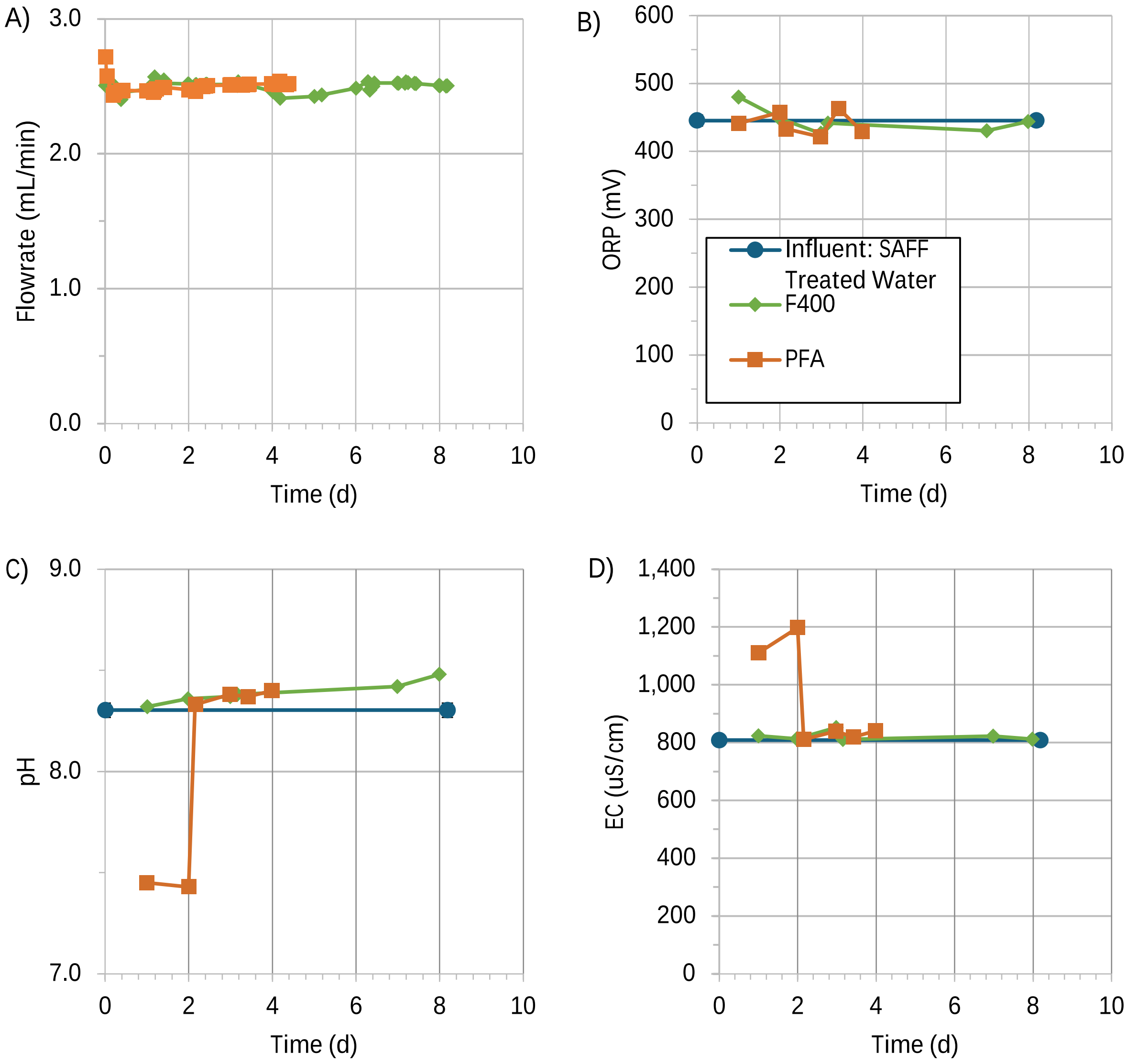

Figure H.54: A) Flowrate, B) ORP, C) pH, and D) EC Results for SAFF® Treated Shakopee Aquifer Groundwater Effluents.

Water chemistry results for inorganic constituents such as alkalinity, hardness, anions, total and dissolved metals, total suspended and dissolved solids for SAFF® samples are presented in Table H.20. Alkalinity, total hardness, and anion (chloride, nitrate, and sulfate) concentrations remained mostly unchanged between the influent and effluent samples. Total and dissolved calcium and magnesium also showed little deviance between the influent and effluent samples. Total and dissolved iron were undetected among all samples. Total manganese in the initial influent was just above the 0.5 µg/L detection limit at 0.51 µg/L; all other samplers were below the detection limit. Dissolved manganese had detections of 0.53 µg/L in the middle influent sample and 0.54 µg/L in the final PFA effluent sample but was below the detection limit in other samples. TSS for influent samples was lower than the effluent samples for both F400 (2.92 mg/L) and PFA (1.36 mg/L). TDS, however, remained relatively unchanged between influent and effluent samples.

Table H.20: General Water Chemistry and Metals Concentrations for SAFF® Treated Shakopee Aquifer Groundwater Samples.

Parameter	Units	Influent Samples		F400 Effluent		PFA Effluent	
		Initial	Middle	Initial	Final	Initial	Final
Alkalinity, Total as $CaCO_3$	mg/L	216	222	217	213	220	214
Total Hardness	mg/L	299	295	293	298	291	288
Chloride	mg/L	139	136	-	132	-	137
Nitrate as Nitrogen	mg/L	2.3	2.3	-	2	-	2.3
Sulfate	mg/L	12.9	13	-	12.6	-	13.1
Calcium	mg/L	80.0	77.7	-	79.5	-	83.5
Iron	µg/L	<50	<50	-	<50	-	<50
Magnesium	mg/L	24.1	23.5	-	24.2	-	24.7
Manganese	µg/L	0.51	<0.5	-	<0.5	-	<0.5
Calcium, Dissolved	mg/L	83.2	84.7	-	82.6	-	84.7
Iron, Dissolved	µg/L	<50	<50	-	<50	-	<50
Magnesium, Dissolved	mg/L	24.4	25.6	-	24.6	-	24.7
Manganese, Dissolved	µg/L	<0.5	0.53	-	<0.5	-	0.54
TSS	mg/L	0.12	< 0.057	-	2.92	-	1.36
TDS	mg/L	488	477	-	456	-	478

H4.2.5 RSSCT Results Summary

The RSSCT evaluation characterized the breakthrough profiles of F400 and PFA for multiple PFAS compounds for four different influent waters. Results indicate PFA IX resin was the more efficient sorbent at removing PFAS, with longer specific throughputs observed for all four water sources than F400 GAC. WCL shallow groundwater contained the highest total concentrations of PFAS and therefore demonstrated the lowest specific throughput for both sorbent columns. RSSCT results indicate use of a sorbent only treatment train at WCL would result in high usage rates of adsorbent media and correspondingly high treatment cost. Results also indicate that, for all waters tested, PFOA is the most difficult PFAS to treat due to its influent concentration and its lower affinity towards adsorption. The specific throughputs obtained in this RSSCT may be used to determine the longevity of the media under pilot-scale or full-scale conditions, by assuming the same empty bed contact times as in the RSSCT (Table H.12). The site-scale flowrate and vessel size (and bed size) may then be used to determine the changeout time for each media and thus estimate the costs of operating the system on an annual basis.

An illustrative example using specific throughputs calculated in this study is give in Table H.21, which provides an example calculation for estimating changeout frequency per year for a typical pilot-test operation. Specifically, this assumes media vessels of 40 cubic feet (ft^3), or 611 kg of media at a bulk density of 0.54 kilograms per liter (kg/L), for GAC and 20 ft^3, or 382 kg at a bulk density of 0.675 kg/L) for the IX resin, and a process flowrate of 25 gallons per minute (gpm), or 136,260 liters per day (L/D).

Table H.21: Limiting Specific Throughputs with Extrapolation for Full-Scale – Pilot-Scale Example Calculation.

Parameter	Units	Jordan Aquifer		SAFF® Treated Shakopee Aquifer		Shakopee Aquifer		WCL	
		F400	PFA	F400	PFA	F400	PFA	F400	PFA
Specific Throughput	L/kg	4,364	> 153,068	25,928	> 152,337	22,000	81,342	< 4,391	< 6,723
Bed Life	days	20	> 429	116	> 427	99	228	< 20	< 19
Changeout Frequency per year	#/yr	19	< 1	4	< 1	4	2	> 19	> 20

Using the limiting specific throughputs obtained in this treatability study, the estimated media longevities for Jordan Aquifer water were 20 and >429 days for the GAC and IX resin, respectively. This translates to 19 and <1 change outs per year for the GAC and the IX resin. Note that because PFAS did not breakthrough the PFA IX resin during the RSSCT, the actual specific throughput would be expected to be larger than what was measured in this study. This constitutes a substantial difference in change out frequencies. However, these differences are smaller for the Shakopee Aquifer, where the GAC is estimated at four changeouts per year versus two changeouts per year for the IX resin. Differences in influent PFAS composition, such as is seen between the raw water from the Shakopee and Jordan Aquifers, can significantly impact media usage.

These results also provide a comparison of SAFF® treated groundwater versus raw groundwater. While there was negligible difference in the estimated GAC life, due to breakthrough of PFOA in the SAFF® Treated Shakopee Aquifer, a significant improvement in IX media life was observed with SAFF® Treat Shakopee Aquifer water. No breakthrough was observed above regulatory limits during the SAFF® Treated Shakopee Aquifer RSSCT, so the true useful IX media life is unknown. Nevertheless, results indicated pretreatment with SAFF® can significantly reduce IX media usage but may not result in significant reductions in GAC usage, dependent on the influent PFAS chemistry.

Lastly, as discussed before, WCL liquid was extremely difficult to treat, resulting in short bed lives that translated to >19 and >20 changeouts per year for the GAC and the IX resin, respectively. It is important to note that the true media life would be significantly shorter, as the first results collected for both GAC and IX exceeded regulatory limits, and in the case of GAC, significantly exceeded regulatory thresholds. Media usage rates are expected to be significantly higher than indicated by these results. Additionally, these estimations highlight how media selection is dependent upon the water matrix to treat, and also whether or not adsorption is the appropriate treatment mechanism.

Although the change out frequency estimations provide a preliminary comparison of the expected media performance in the field, other factors such as media transportation logistics, footprint availability at the Site, potential Site operation and maintenance issues, and costs (both capital expenditures and media costs), play a role in the final treatment technology selection, and should be considered in a technical/economic analysis or a life-cycle assessment. Nevertheless, the bench-scale treatability study provided evidence of substantially different performances between the GAC and IX resin, so that media longevity/performance will likely have a higher weight in the decision-making process for technology selection.

H5 Overall Study Conclusions

The bench-scale treatability study evaluated groundwater pretreatment strategies on the Jordan Aquifer groundwater and PFAS adsorption-based treatment alternatives on all four test waters. PFAS adsorption was evaluated in terms of specific throughputs for flow-through conditions. This evaluation demonstrated IX resin had superior performance compared to GAC for all four test waters. Specific throughputs calculated as part of this study are used in Appendix J (Pump & Treat) and Appendix K (MBWA) to estimate yearly media usage and cost and will help inform selection of an optimal treatment train for PFAS removal.

Specific study objectives and outcomes are summarized in Table H.22.

Table H.22: Treatability Study Objectives and Outcomes.

Objective	Outcome
Determine if Jordan Aquifer drinking water TSS, TOC, iron, manganese, pH adjustment, and free chlorine concentrations are acceptable for adsorption treatment and the best pretreatment process through bench-scale treatability testing	TOC, manganese, pH, and free chlorine were at acceptable levels in the raw groundwater sample. However, TSS and iron were above the water quality criteria suggested by the sorbent vendors. The best pretreatment strategy for the removal of TSS and total iron was a combination of NaOCl and catalytic media (Pyrolusite or GreensandPlus™). Additional testing under a variety of flow regimes at the four groundwater locations may be required to more accurately design and operate pretreatment systems at the media testing scale.
Evaluate the time to breakthrough for PFAS compounds in all media tested	Breakthrough times were obtained for several PFAS species and sorbent combinations. In some cases, no breakthrough was detected for a sorbent. Selected treatment criteria (EPA MCLs, MDH HBV & HRLs, and MPCA SSC) were used to determine breakthrough concentrations. PFOA was generally the limiting factor among the PFAS of concern due to its short breakthrough profiles.
Evaluate the amount of water treated per mass of sorbent (specific throughput rate)	Specific throughputs were obtained for several PFAS species based on breakthrough curves and selected treatment criteria. A minimum specific throughput was obtained depending on the most limiting conditions. F400 and PFA had some specific throughputs higher than (">") the value measured as no breakthrough was observed within the operation of the RSSCTs.
Determine the optimum sorbent(s) for PFAS removal from the impacted water	The optimum sorbent, based on PFAS removal under flow-through conditions, was PFA. It demonstrated better adsorption than F400 for every water source.

Deviations to the original work plan are described below:

- Raw water characterization by AEL was not conducted on the raw waters, which was caused by an oversight in the sampling plan. In lieu of AEL's analyses, historical data was used for the basis of the general chemistry for Jordan Aquifer, Shakopee Aquifer, and SAFF® Treated Shakopee Aquifer groundwaters; no historical data was available for WCL. However, prior to use in RSSCTs, the filtered influent waters used for RSSCTs were characterized. This RSSCT influent is the true representation of what water actually passed through the sorbent media.
- Baseline characterization by AECOM in-house analyses was conducted on Jordan Aquifer groundwater upon arrival for the pretreatment processes; however, Shakopee Aquifer, WCL, and SAFF® treated Shakopee Aquifer groundwater characterization did not occur till the end of the project.
- Manganese pretreatment evaluations for Jordan Aquifer water were omitted due to meeting the water quality criteria in the raw groundwater.
- GreensandPlus™, which has a proven record for iron removal from water, was selected over quartz sand as a catalytic media to pretreat Jordan Aquifer water.

- H_2O_2 and NaOCl were added to the pretreatment evaluation to account for the high concentration of iron. In addition, $KMnO_4$ was decoupled from the catalytic media and NaOCl was used instead. The oxidant switch with the catalytic media was decided as past AECOM pretreatment studies showed good iron removal with NaOCl.
- Aeration was omitted from the pretreatment evaluation as the oxidation strength of $KMnO_4$, H_2O_2, and NaOCl, which are higher than aeration, did not oxidize the iron to below the 0.1 mg/L limit.

General observations:

- Jordan Aquifer iron concentrations were below the detection limit upon arrival to the AECOM laboratories; therefore, an iron spike was added to the groundwater to perform the pretreatment tests.
- WCL groundwater was the most difficult groundwater to treat, due to very high concentrations of PFAS compounds, specifically PFOA and PFBA.
- PFOA was the most difficult compound to treat to regulatory limits for both F400 and PFA. The regulatory limit for PFOA is a very low concentration, and the compound is present at high levels in the influent water sources. PFOA is also a carboxylic acid PFAS compound, which has less adsorption affinity than its corresponding sulfonate, PFOS.

In conclusion, the bench-scale treatability study fulfilled its objectives to identify which water quality parameters needed pretreatment for Jordan Aquifer groundwater, the best recommendation of pretreatment strategy based on removal performance for Jordan Aquifer groundwater, and the best recommendation of PFAS sorbent for all waters based on PFAS removal capacity and breakthrough specific throughput. Pretreatment of iron and TSS was required based on the sorbent vendors' recommendations for influent water quality. The best performing pretreatment strategy was NaOCl with either GreensandPlus™ or pyrolusite. PFA IX resin outperformed F400 GAC in terms of PFAS adsorption and removal on a specific throughput basis for all four tested water sources. However, WCL groundwater demonstrated very small specific throughput, which would correspond to a short media life. Use of adsorbent media alone may be insufficient to treat WCL groundwater to applicable regulatory standards.

H6 References

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H7 Additional Figures

H7.1 Jordan Aquifer Plots for Detected Compounds

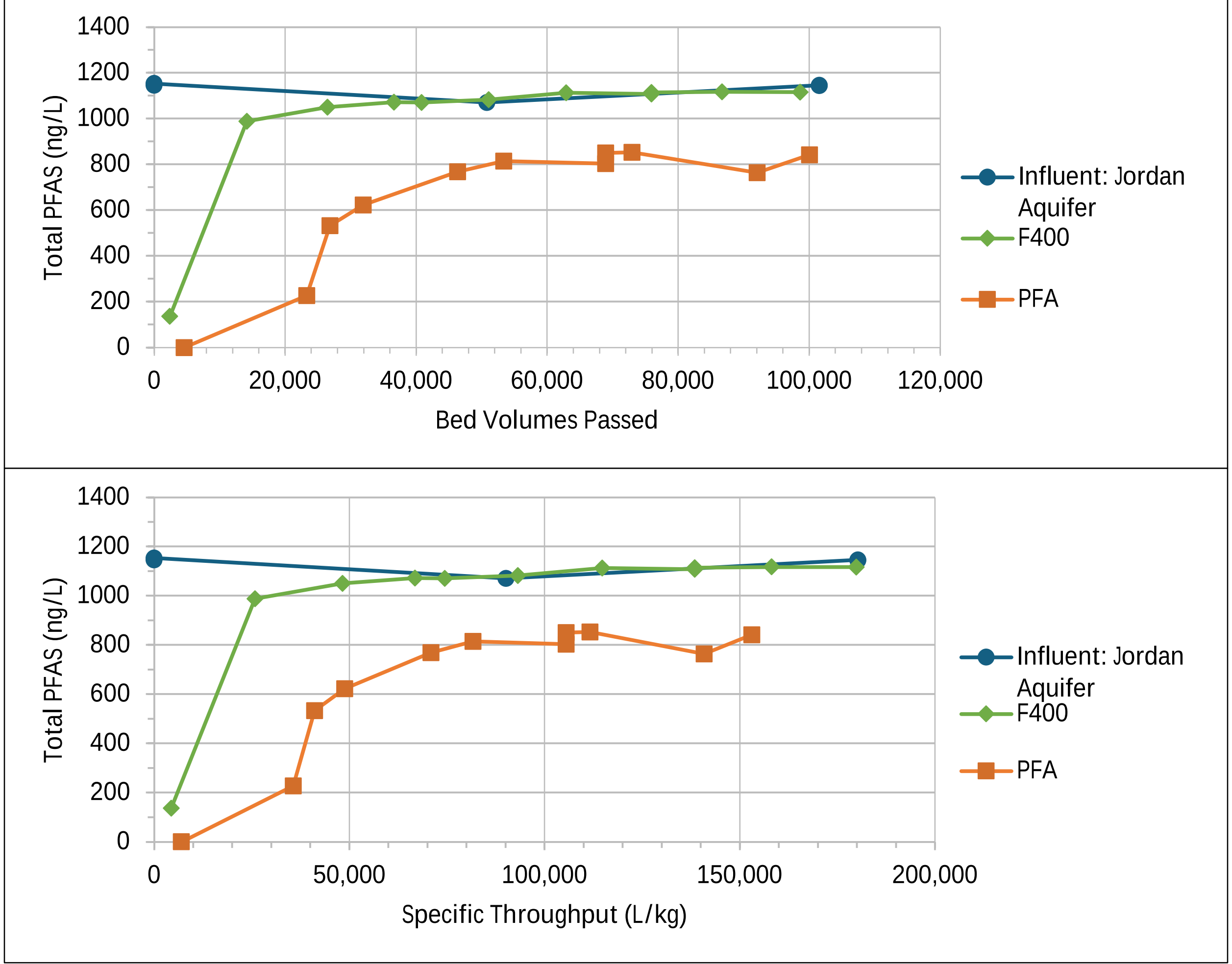


Figure H.55: Total PFAS Concentration vs Bed Volumes & Specific Throughput for Jordan Aquifer.

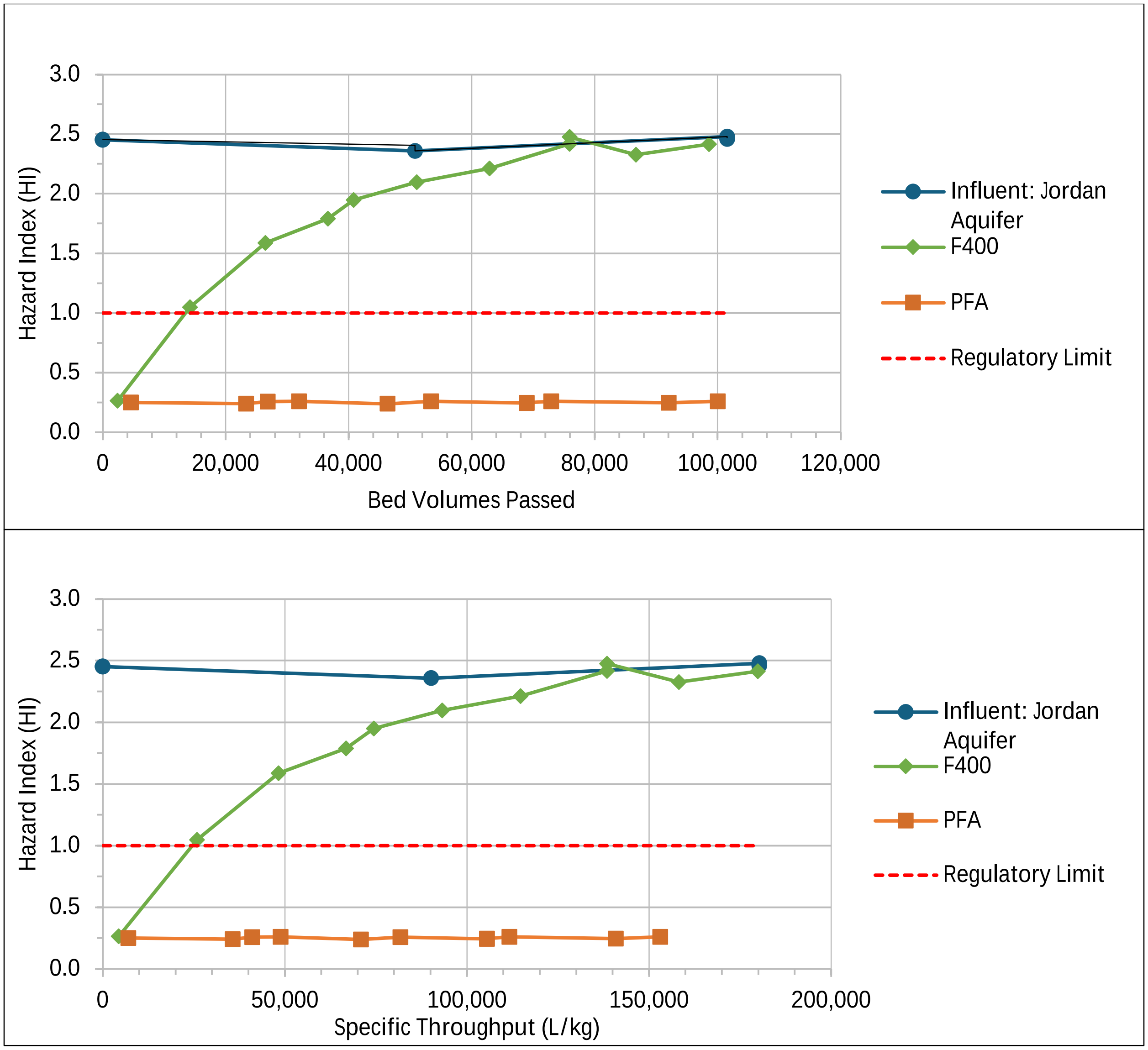


Figure H.56: Hazard Index vs Bed Volumes & Specific Throughput for Jordan Aquifer.

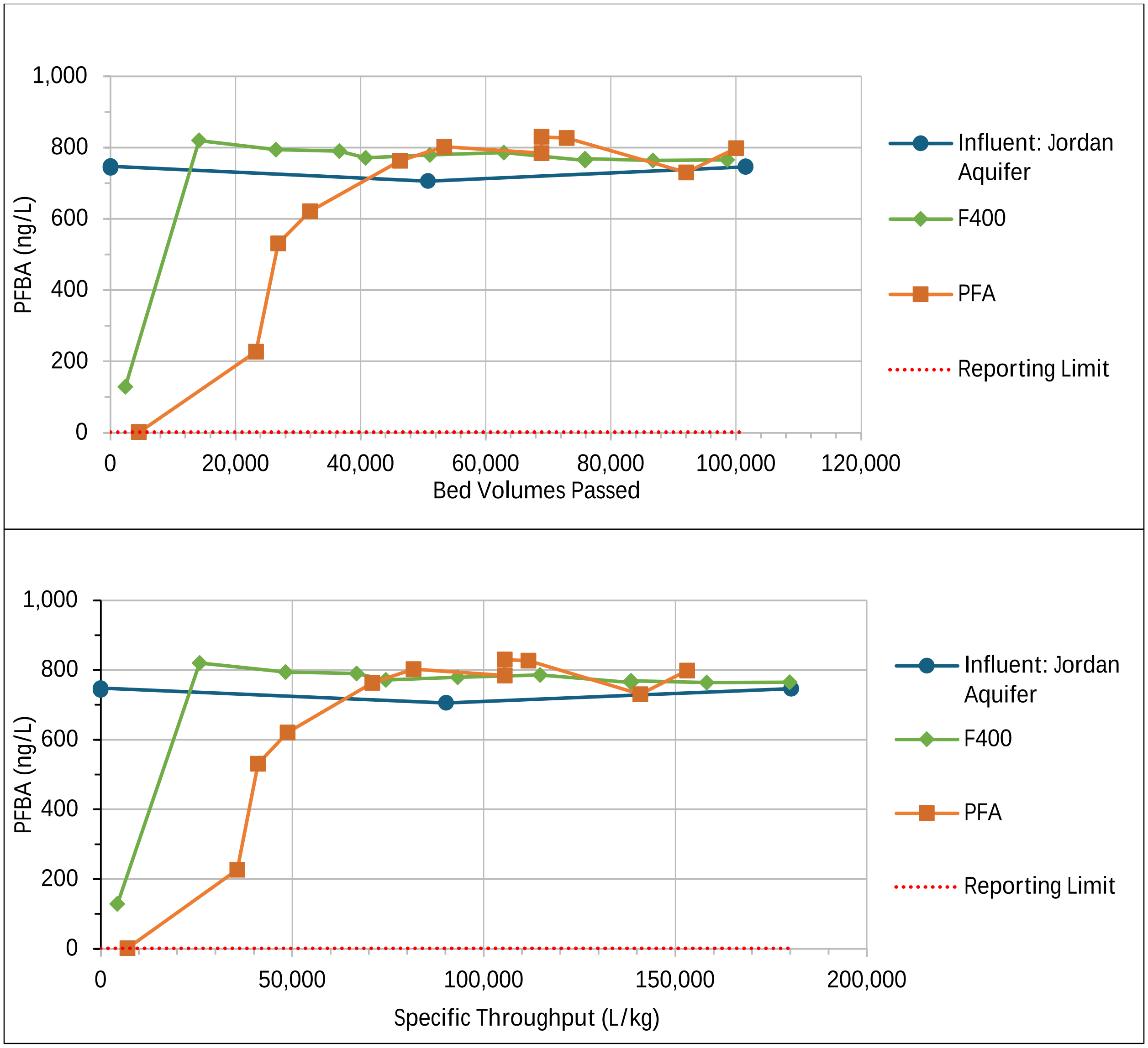


Figure H.57: PFBA Concentration vs Bed Volumes & Specific Throughput for Jordan Aquifer.

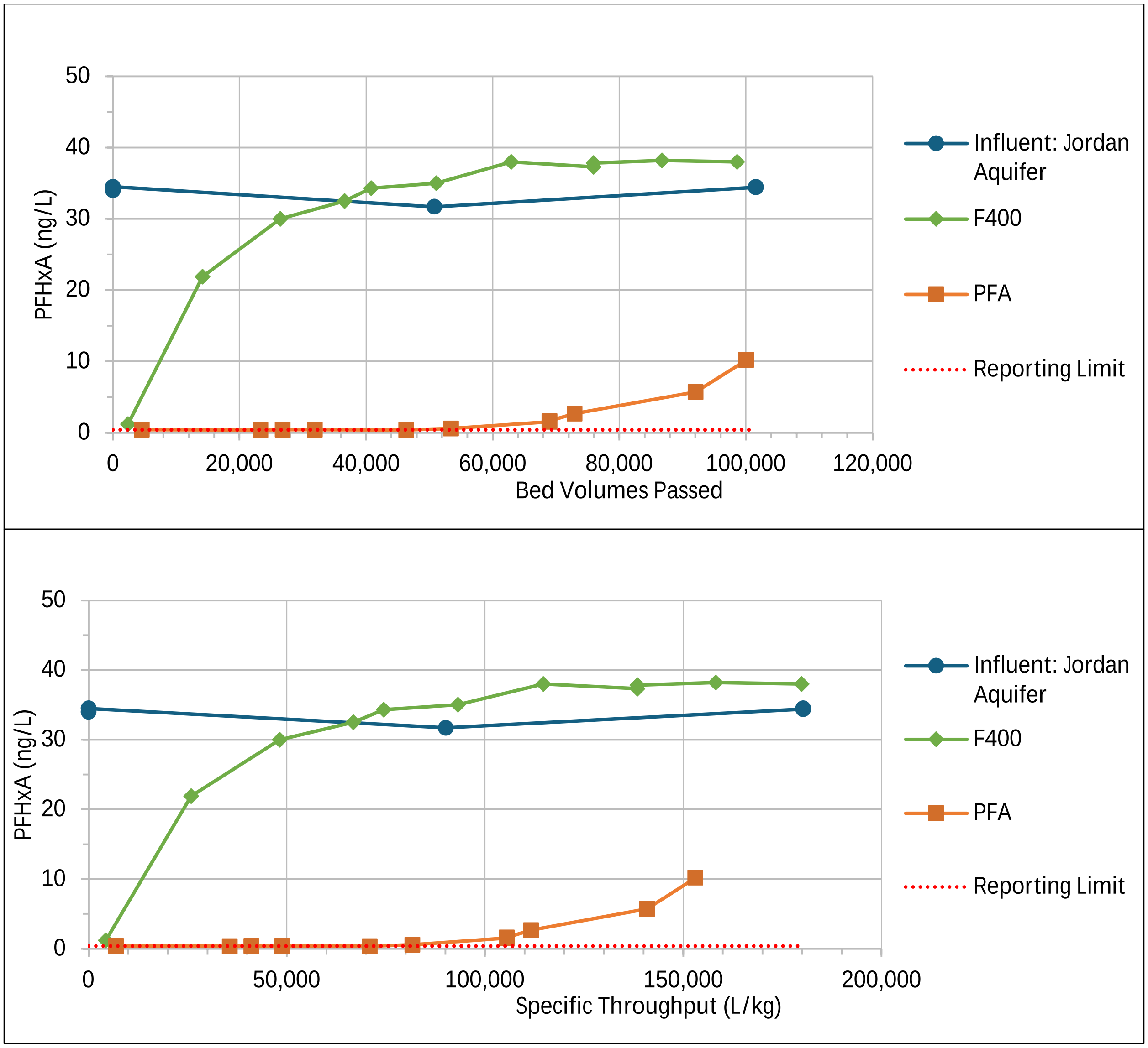


Figure H.58: PFHxA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

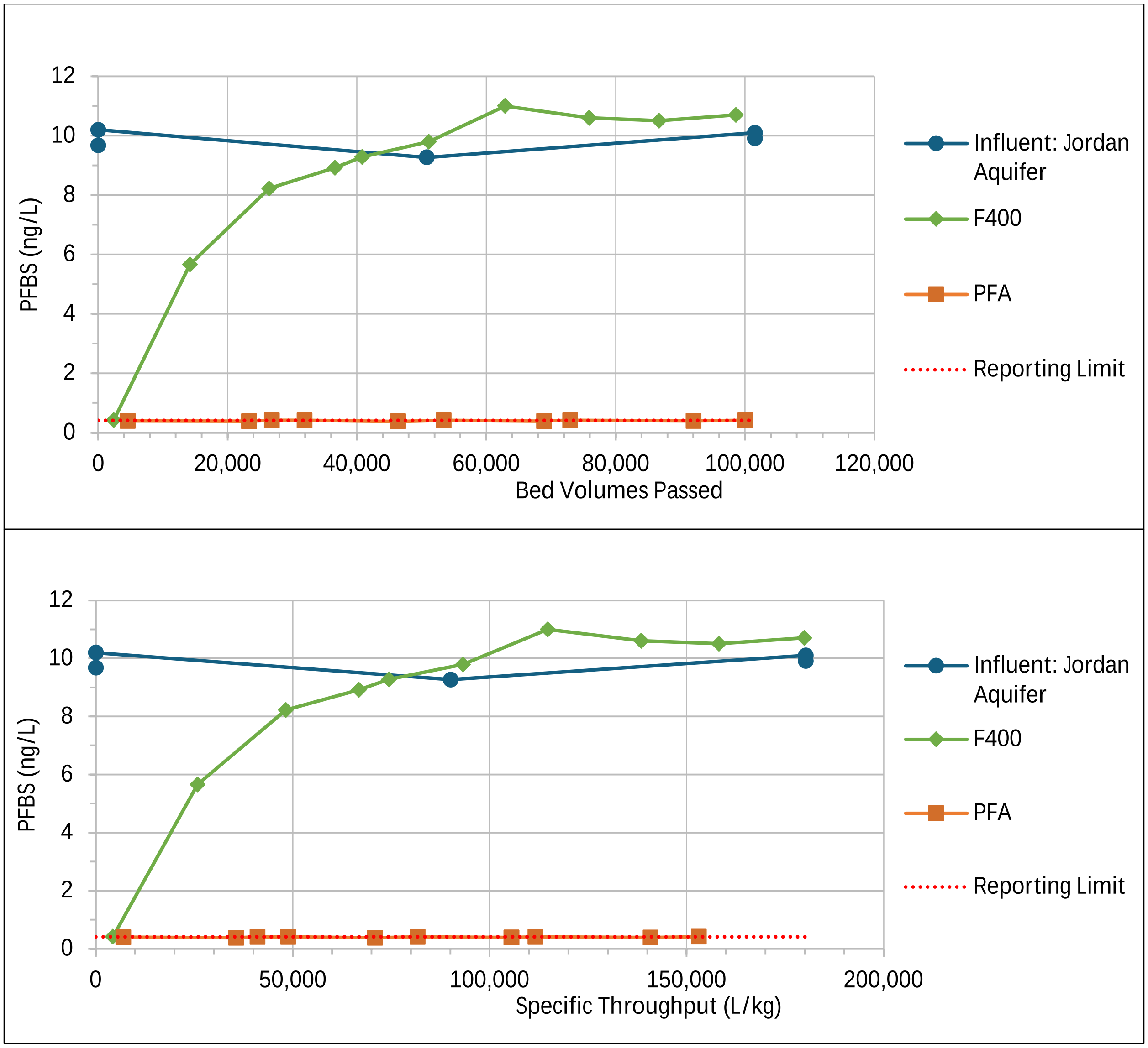


Figure H.59: PFBS Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

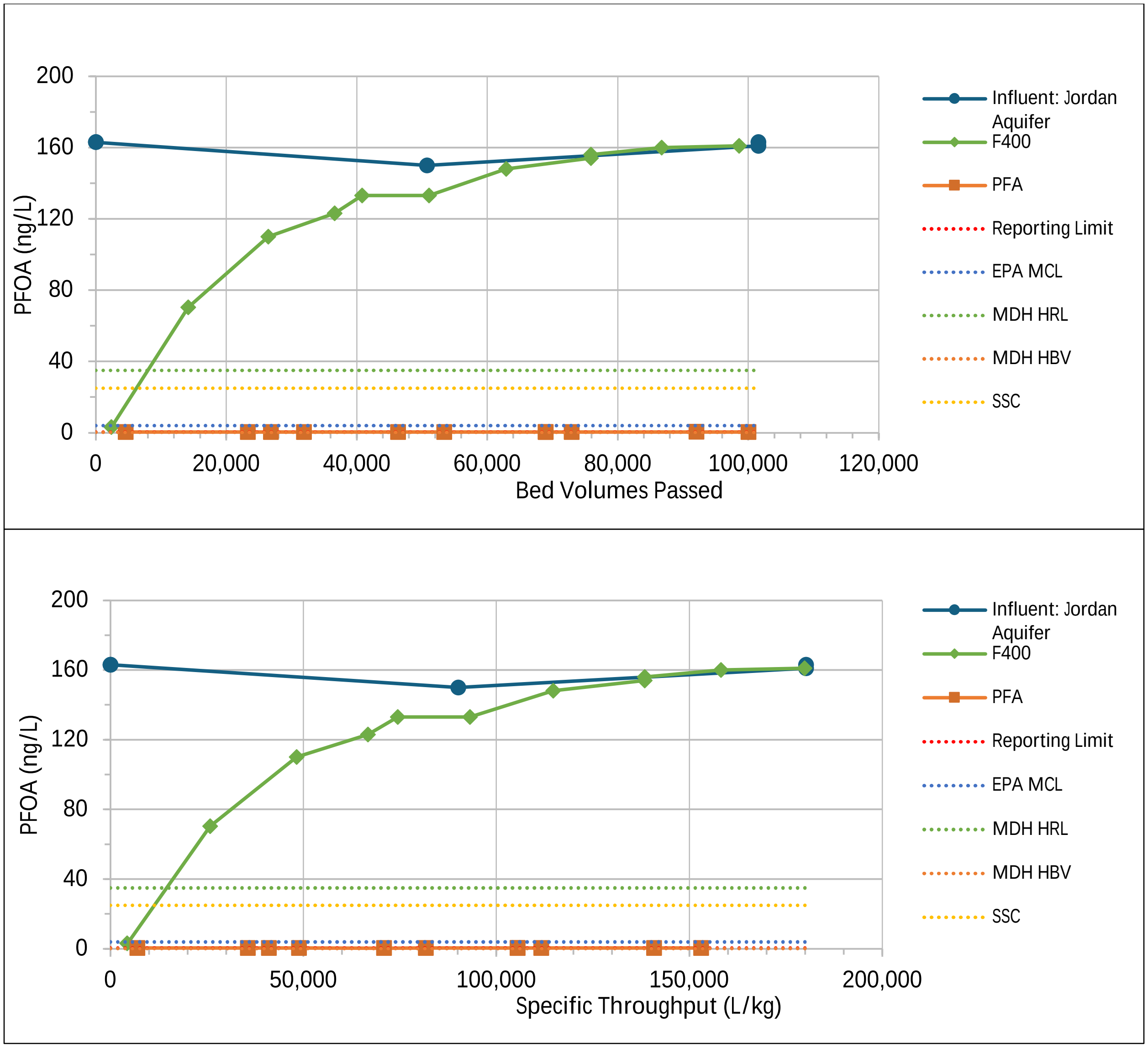


Figure H.60: PFOA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

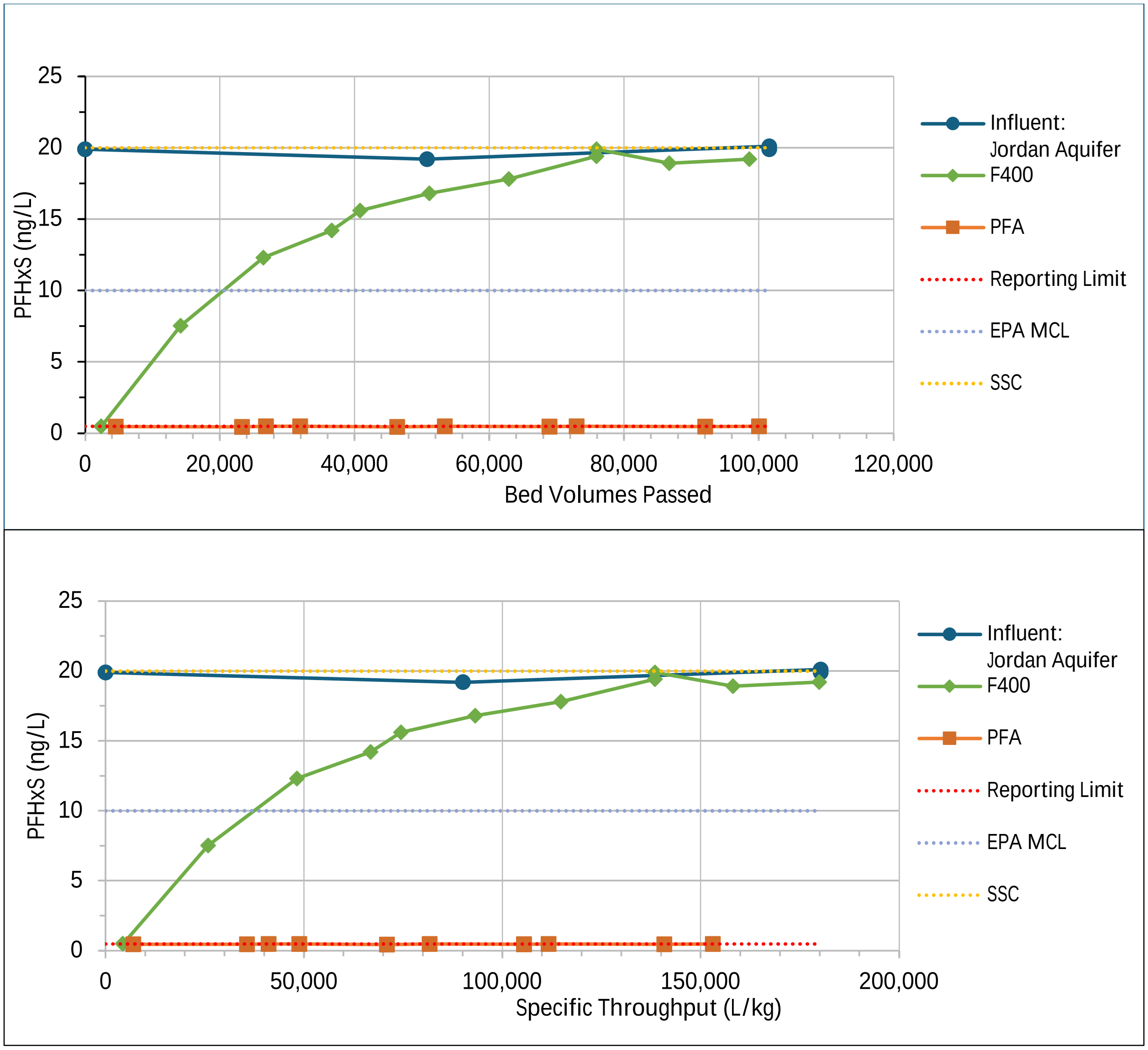


Figure H.61: PFHxS Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

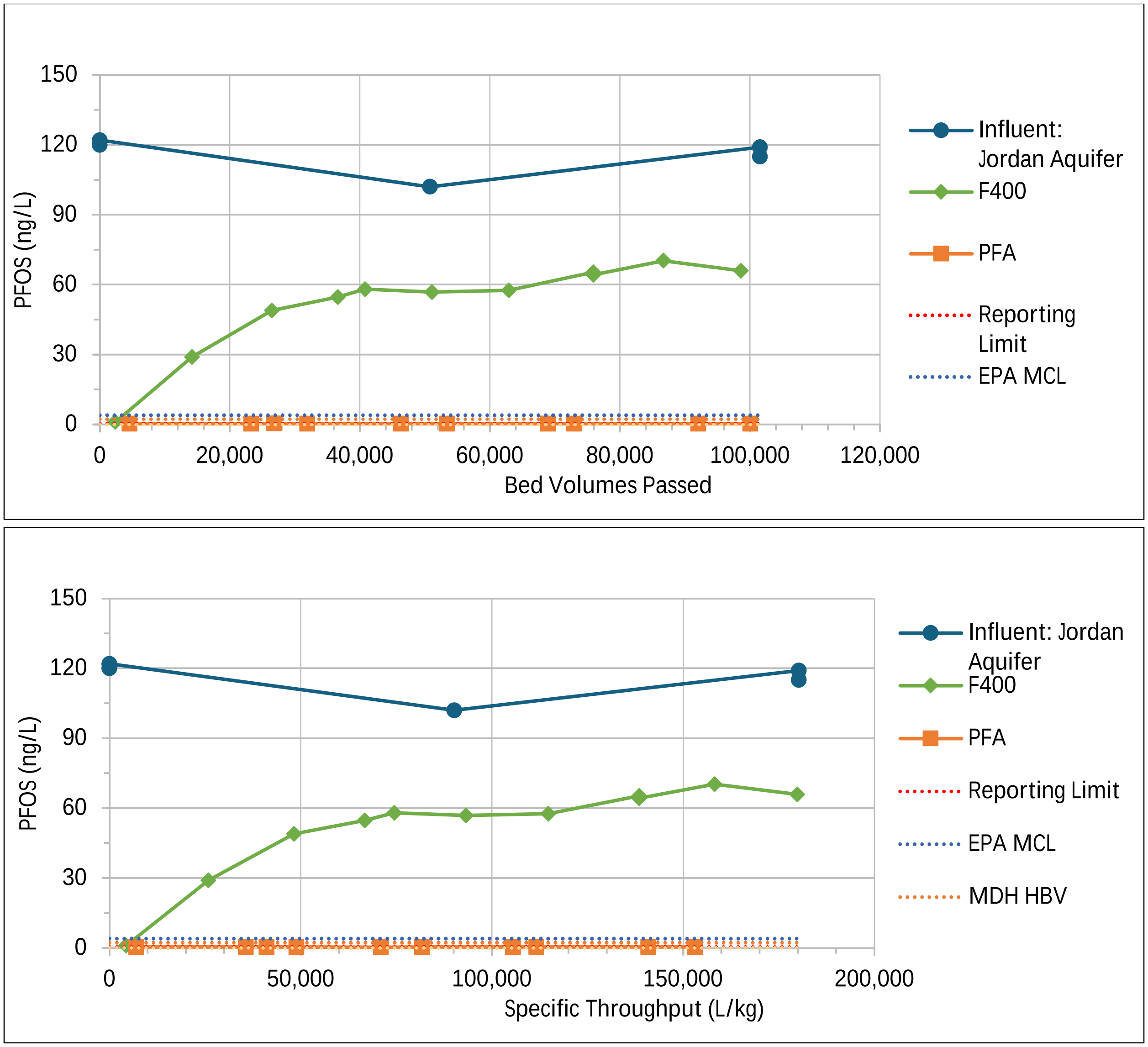


Figure H.62: PFOS Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

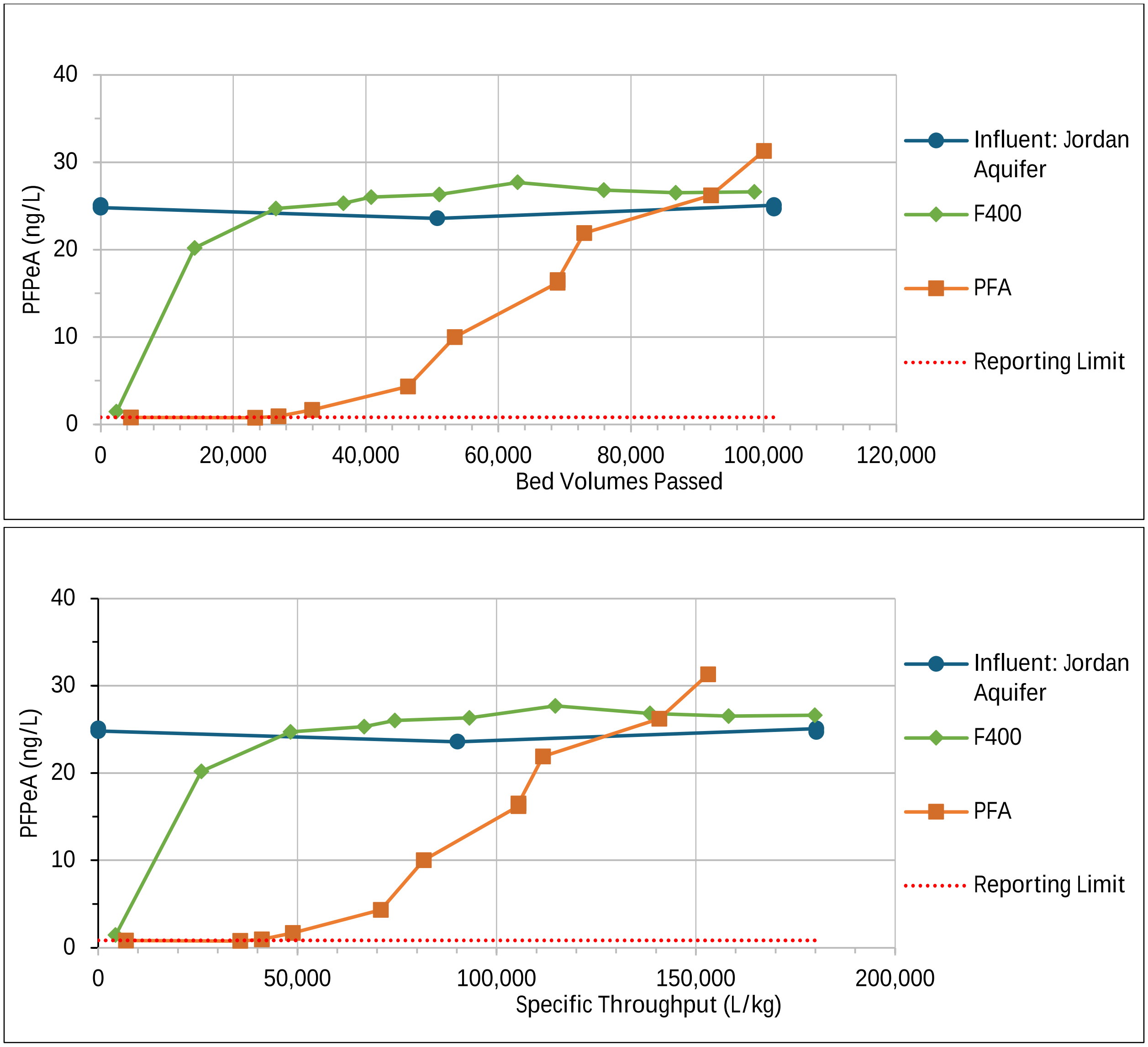


Figure H.63: PFPeA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

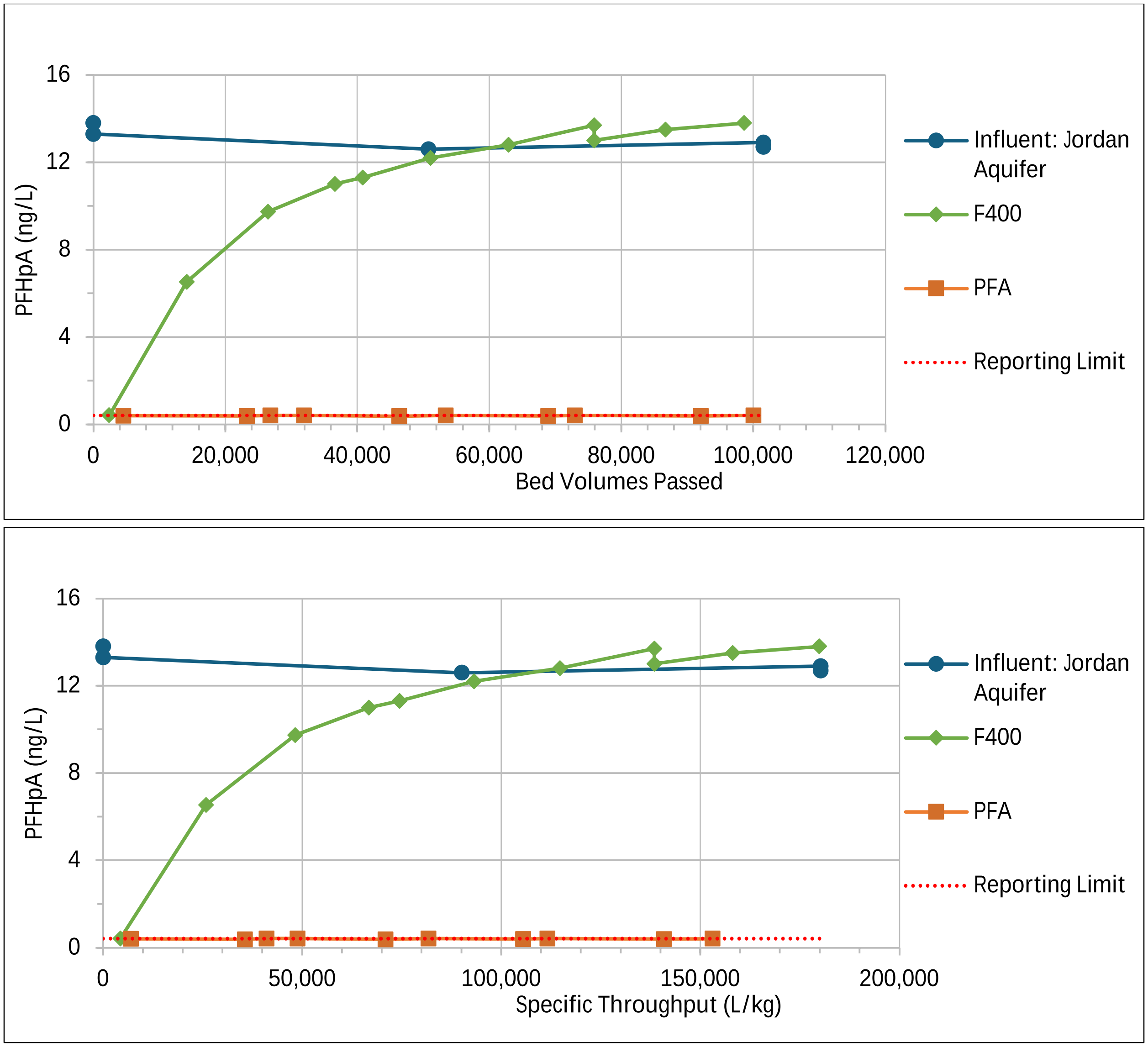


Figure H.64: PFHpA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

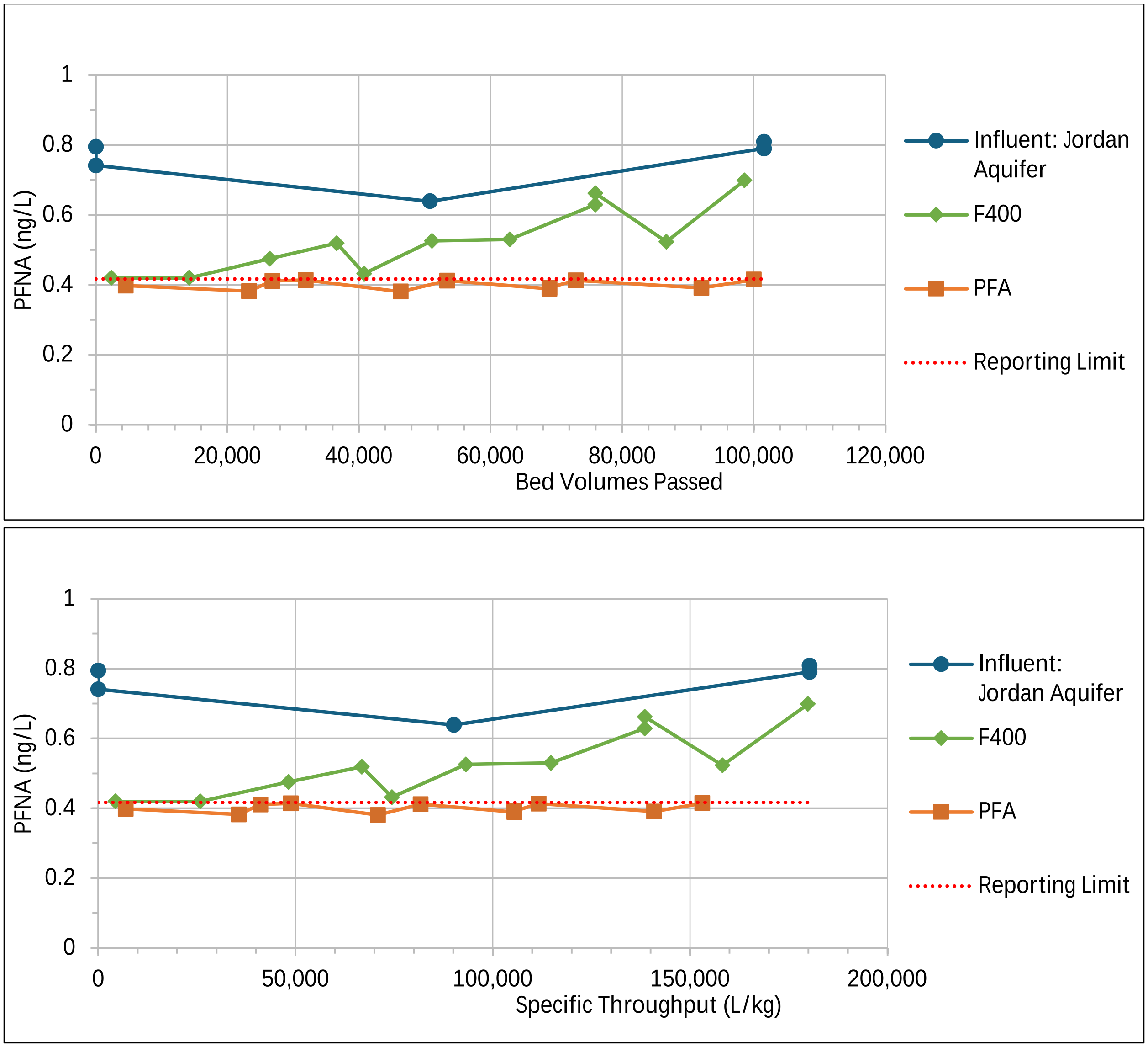


Figure H.65: PFNA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

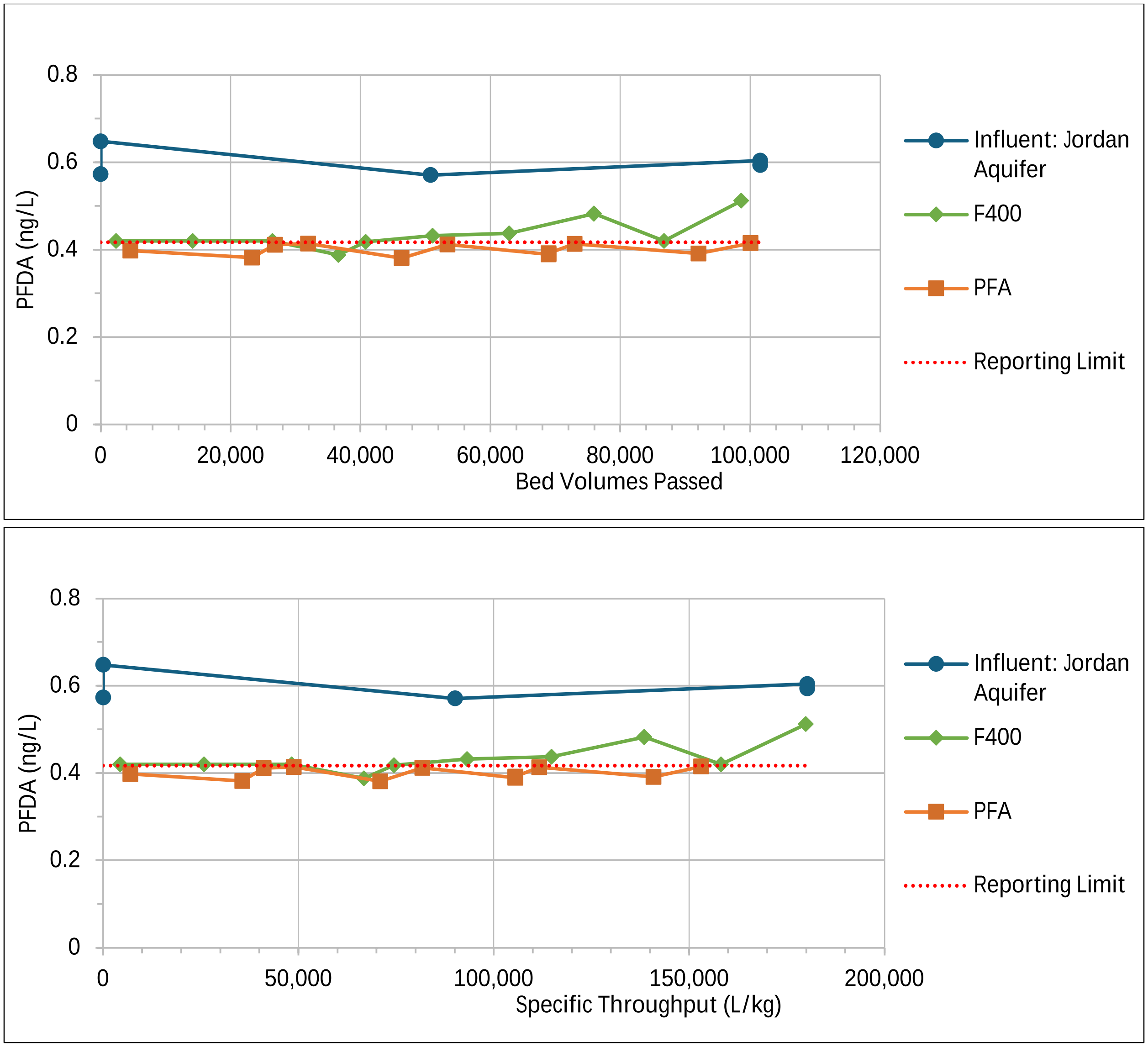


Figure H.66: PFDA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

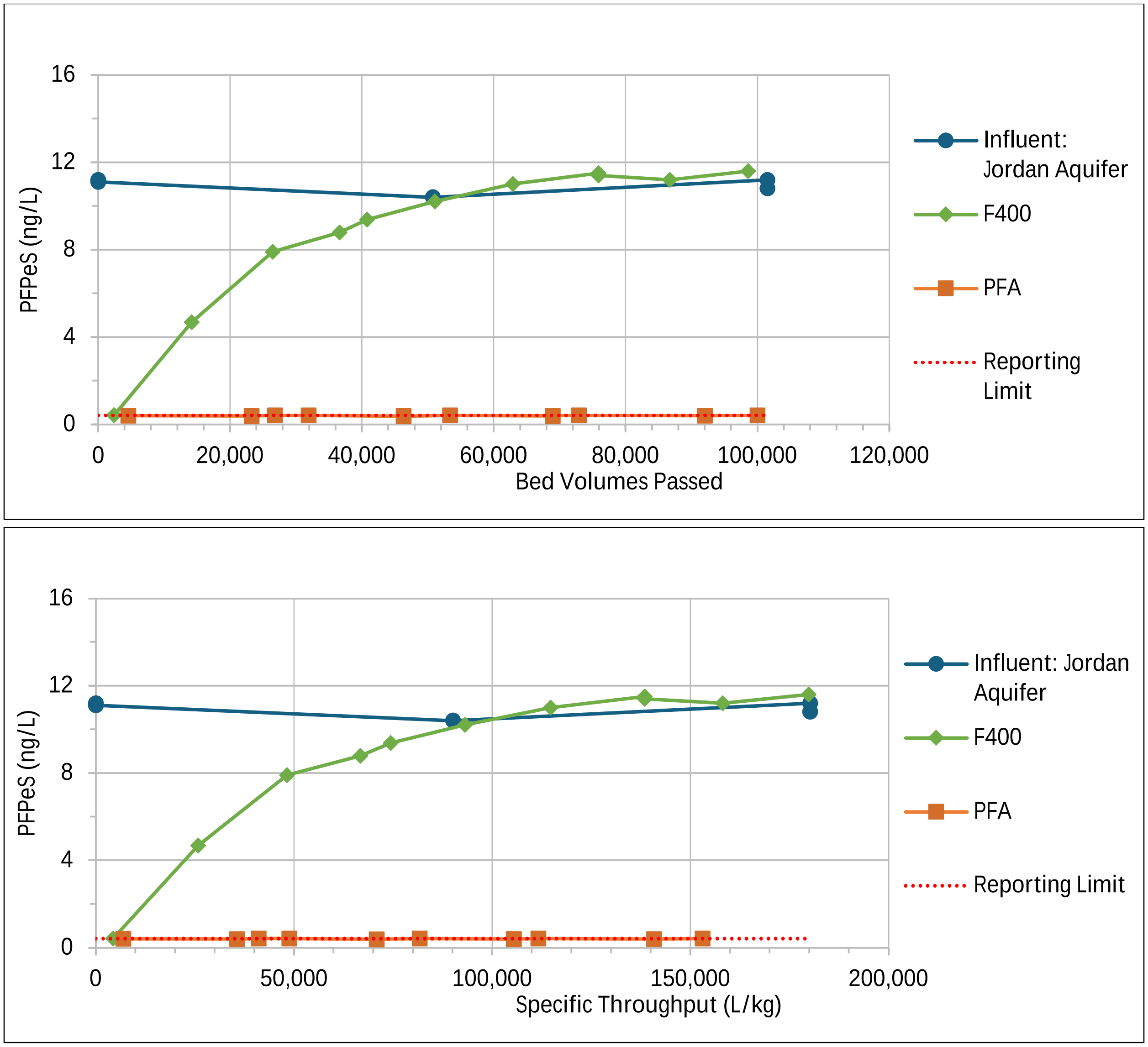


Figure H.67: PFPeS Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

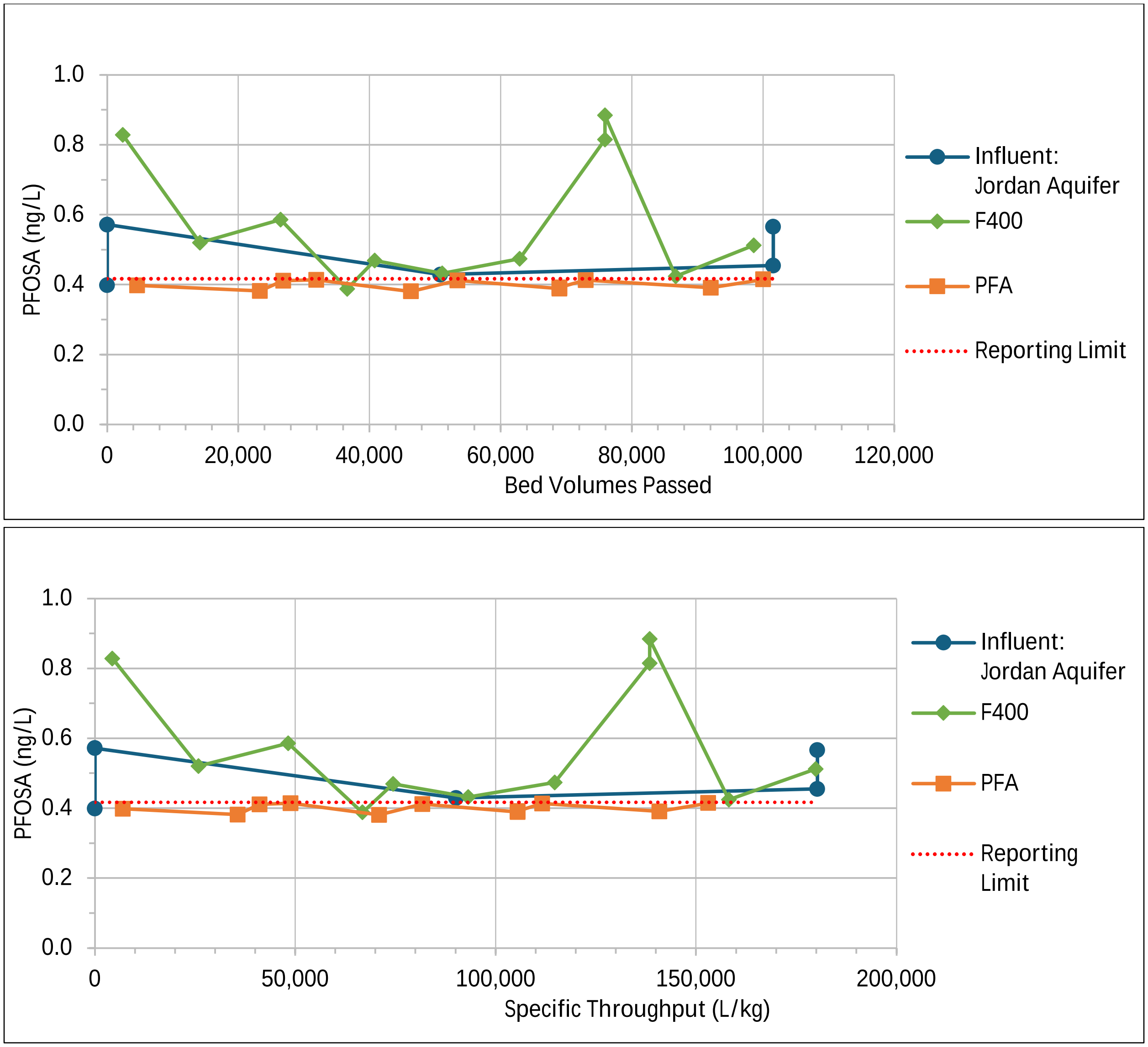


Figure H.68: PFOSA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

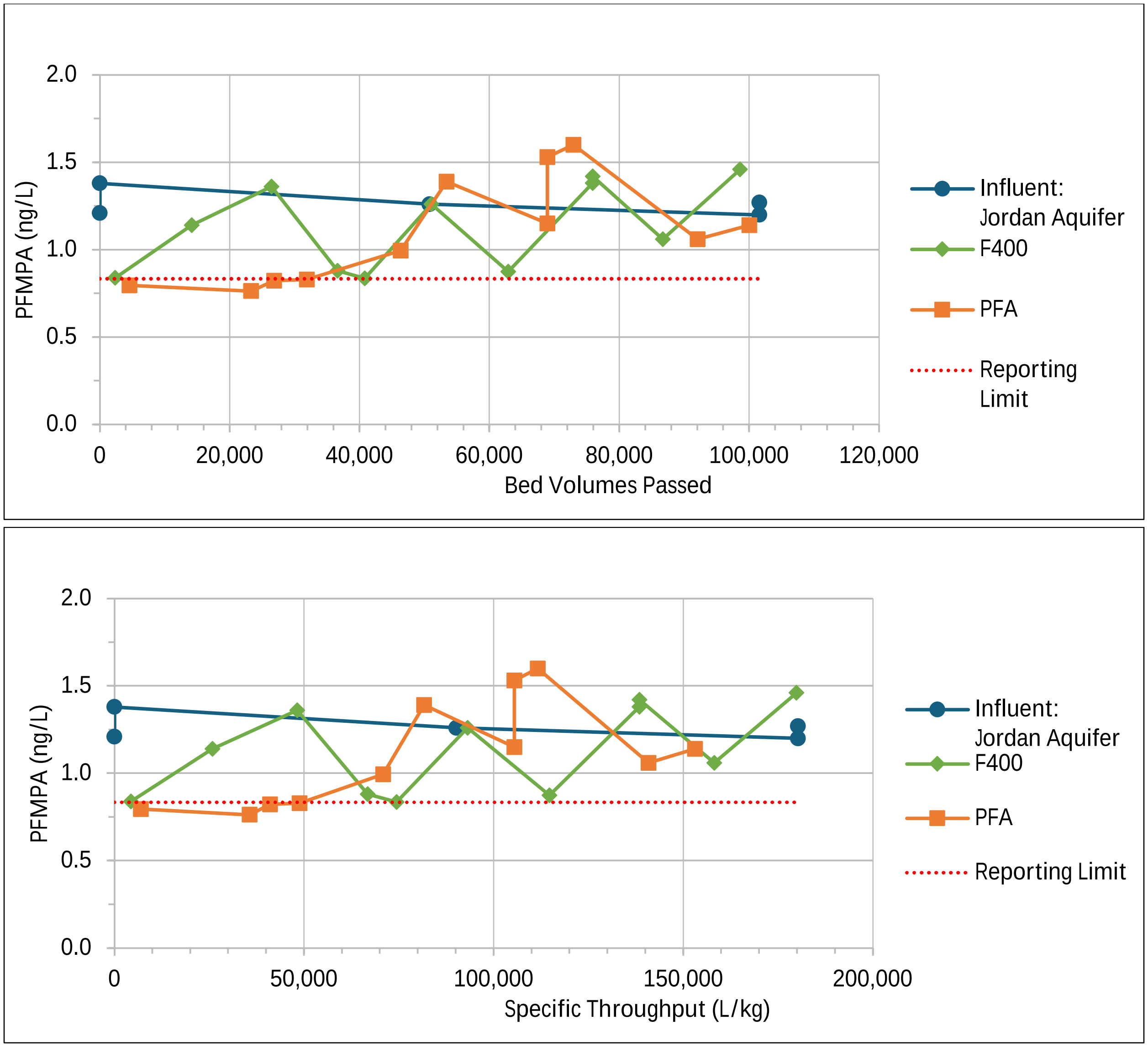
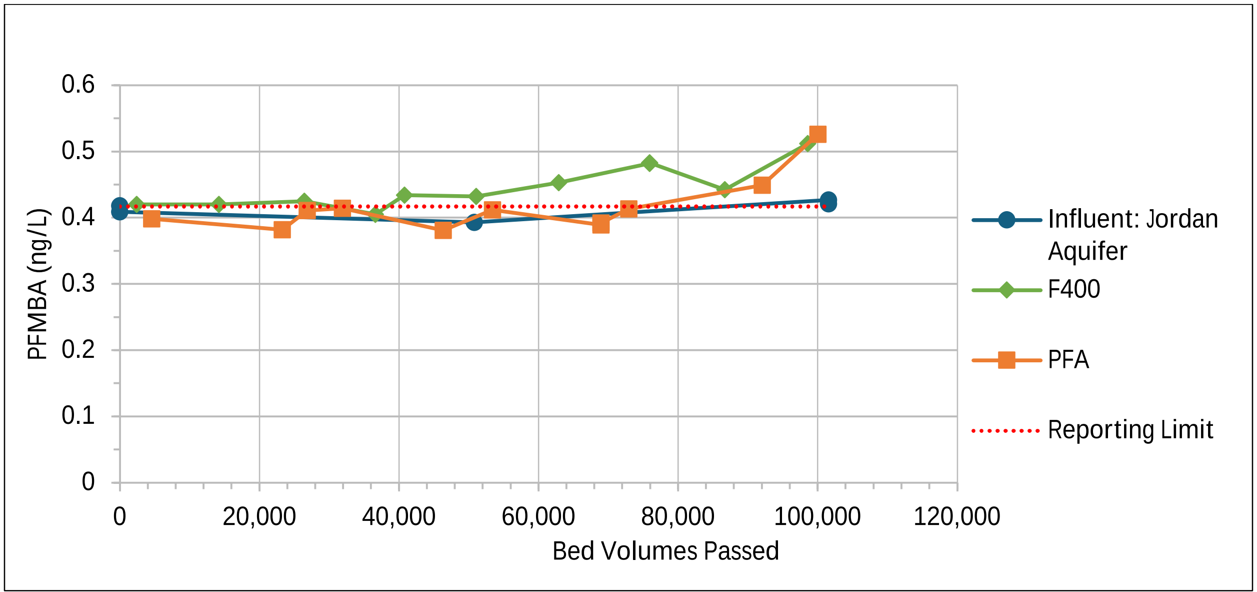


Figure H.69: PFMPA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.



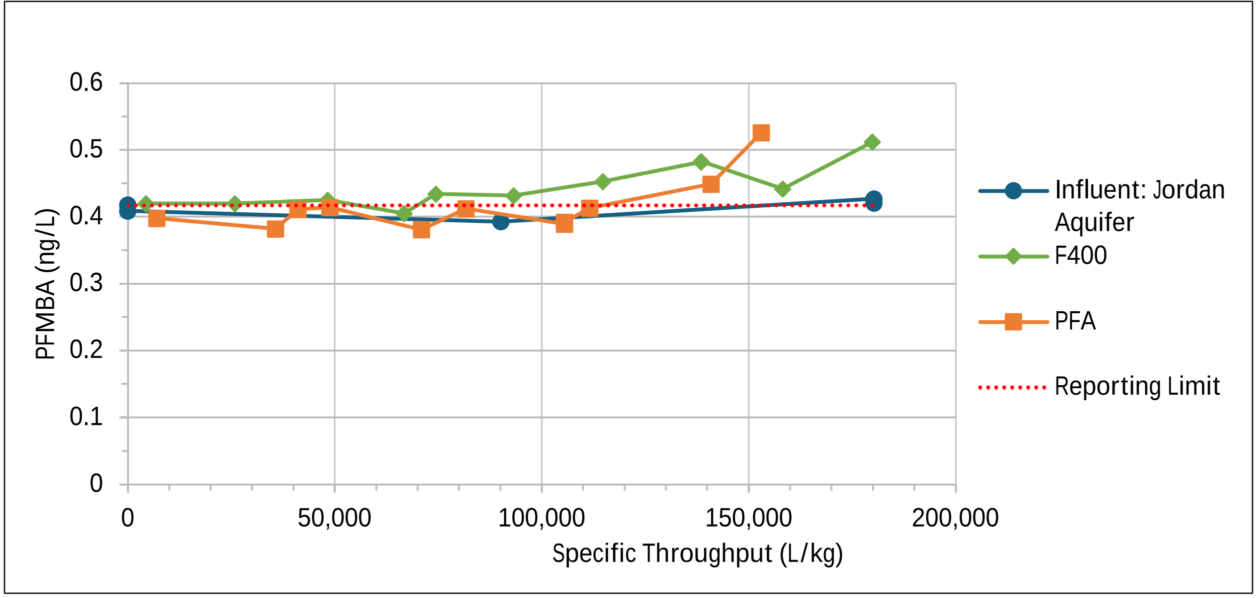


Figure H.70: PFMBA Concentrations vs Bed Volumes & Specific Throughput for Jordan Aquifer.

H7.2 Shakopee Aquifer Plots for Detected Compounds

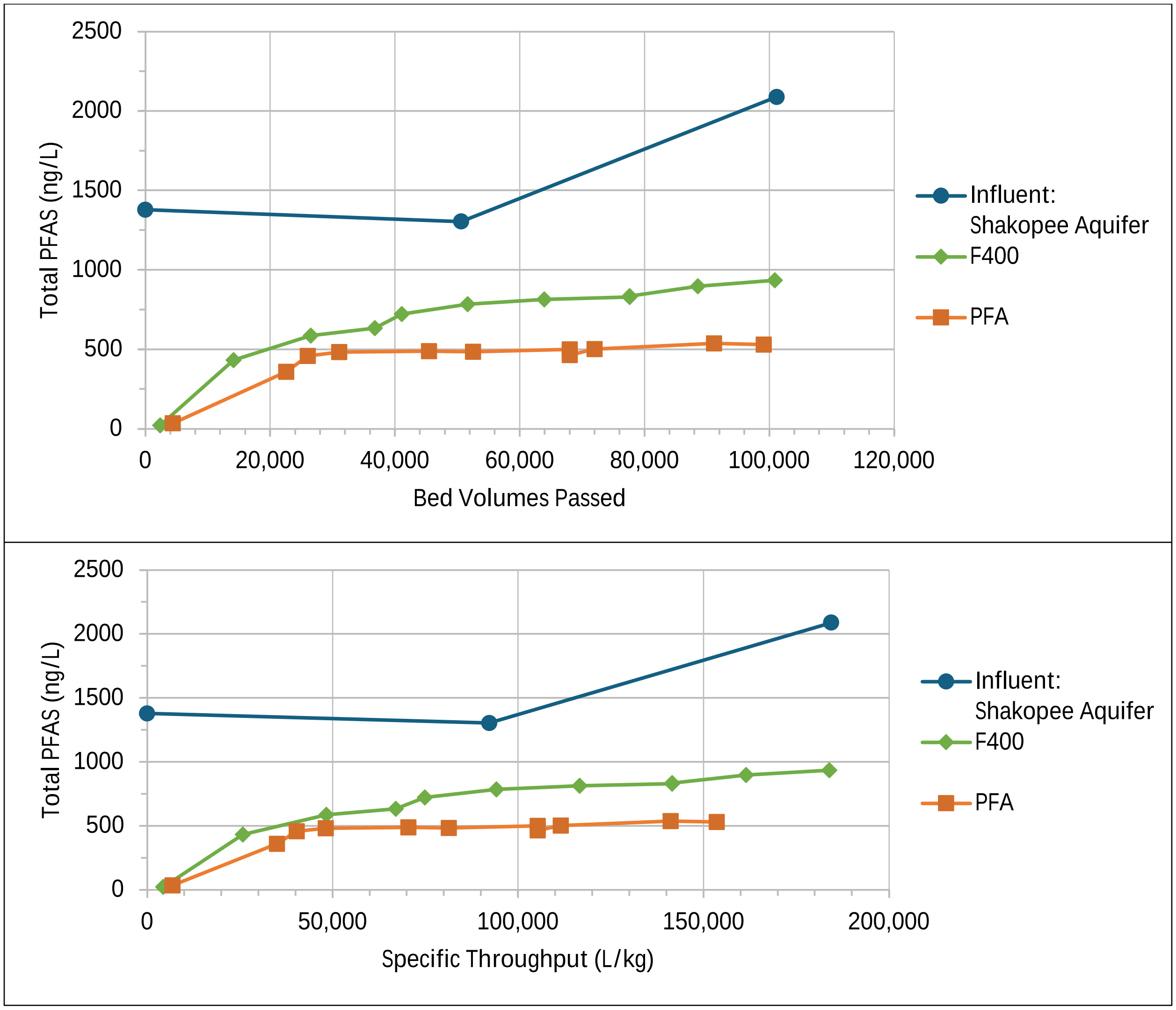


Figure H.71: Total PFAS Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

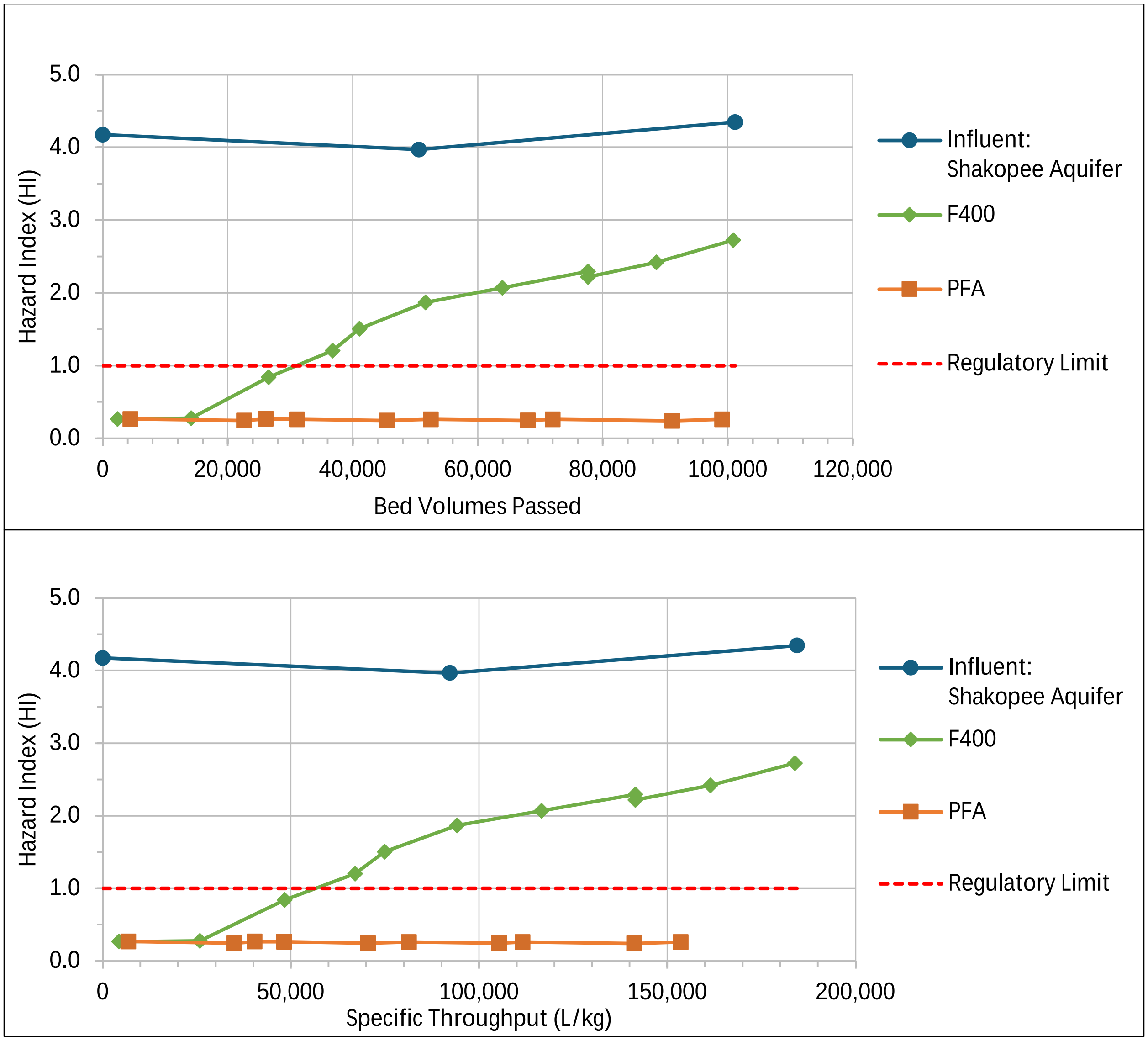


Figure H.72: Hazard Index vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

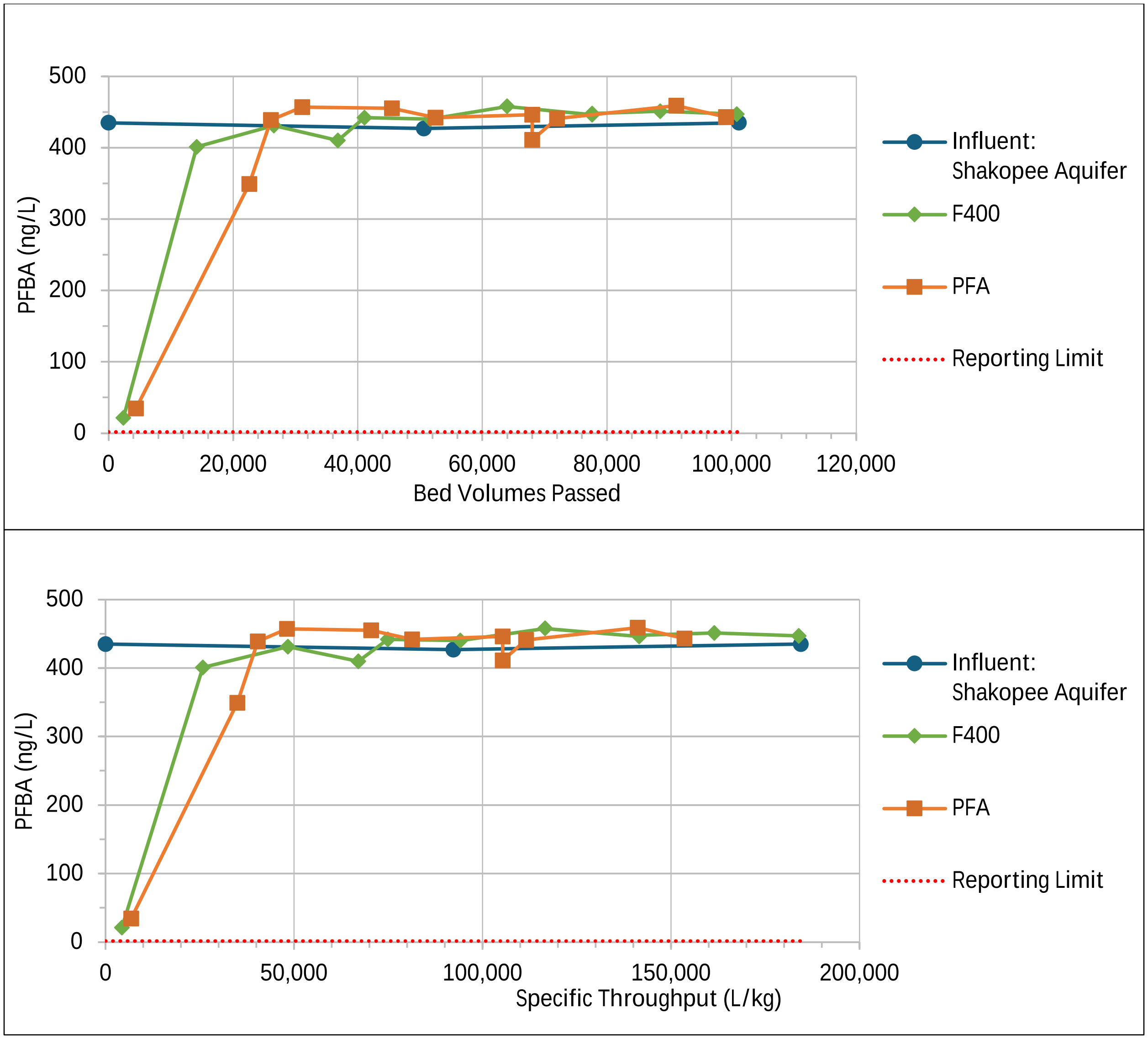


Figure H.73: PFBA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

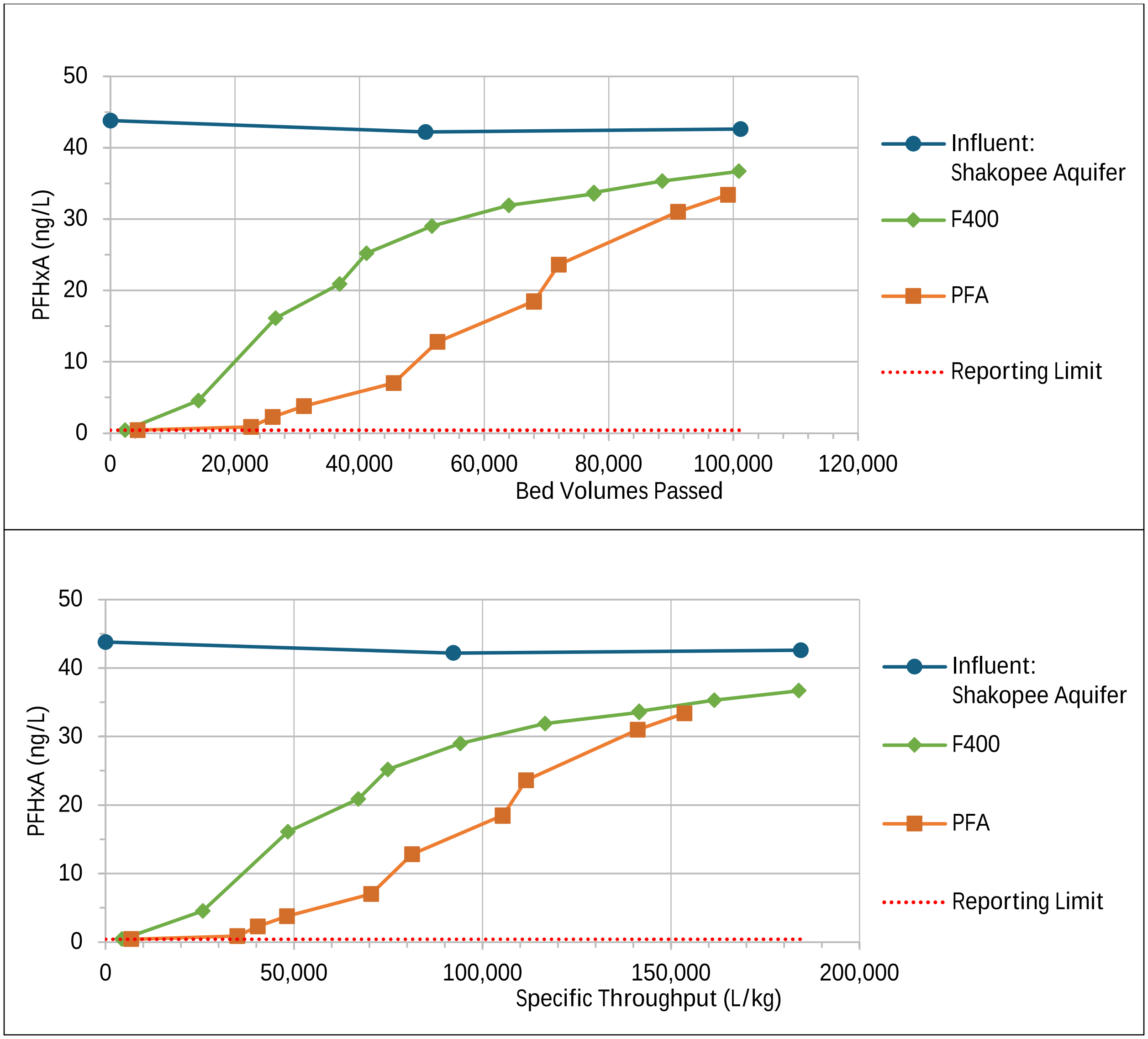


Figure H.74: PFHxA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

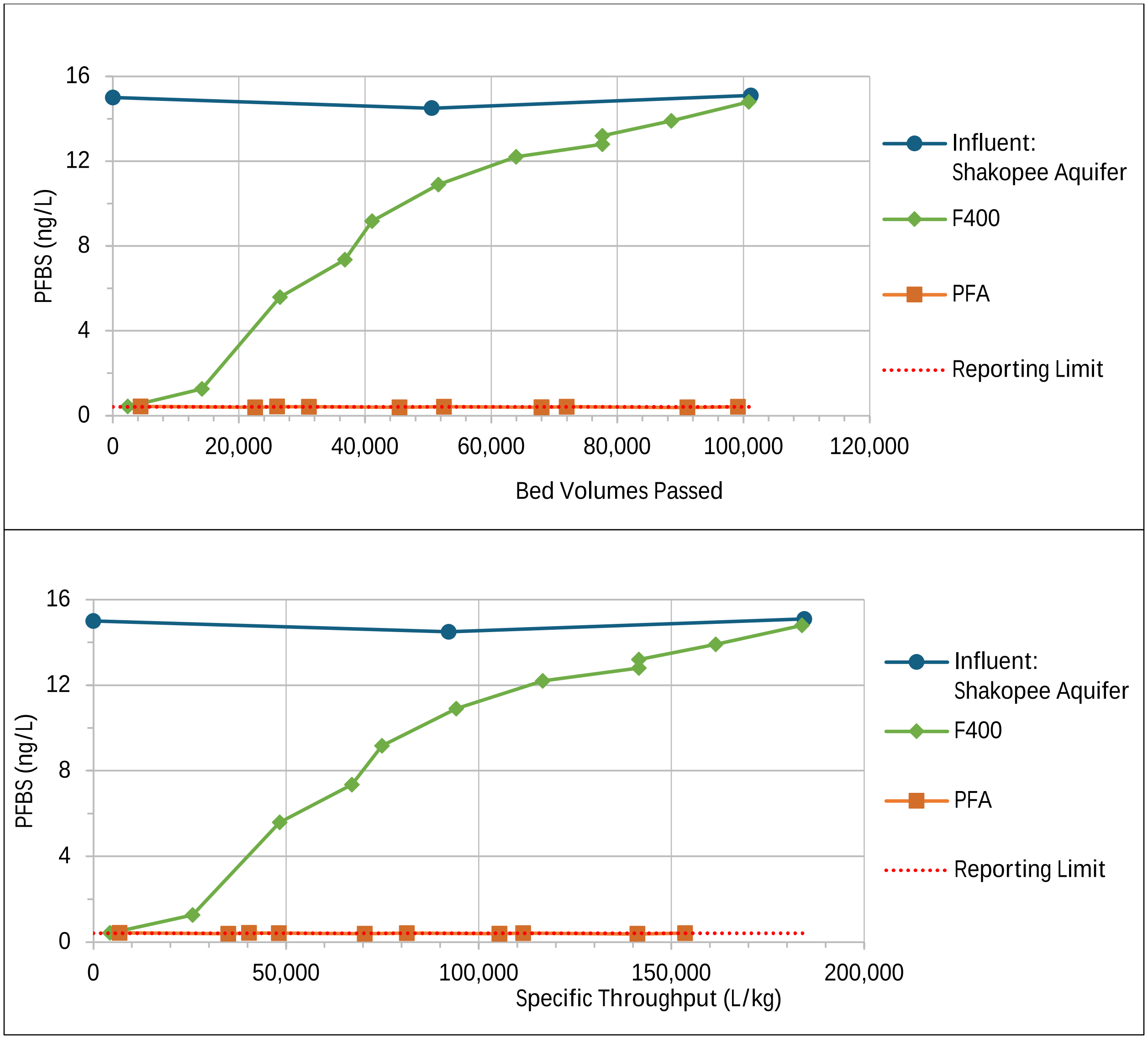


Figure H.75: PFBS Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

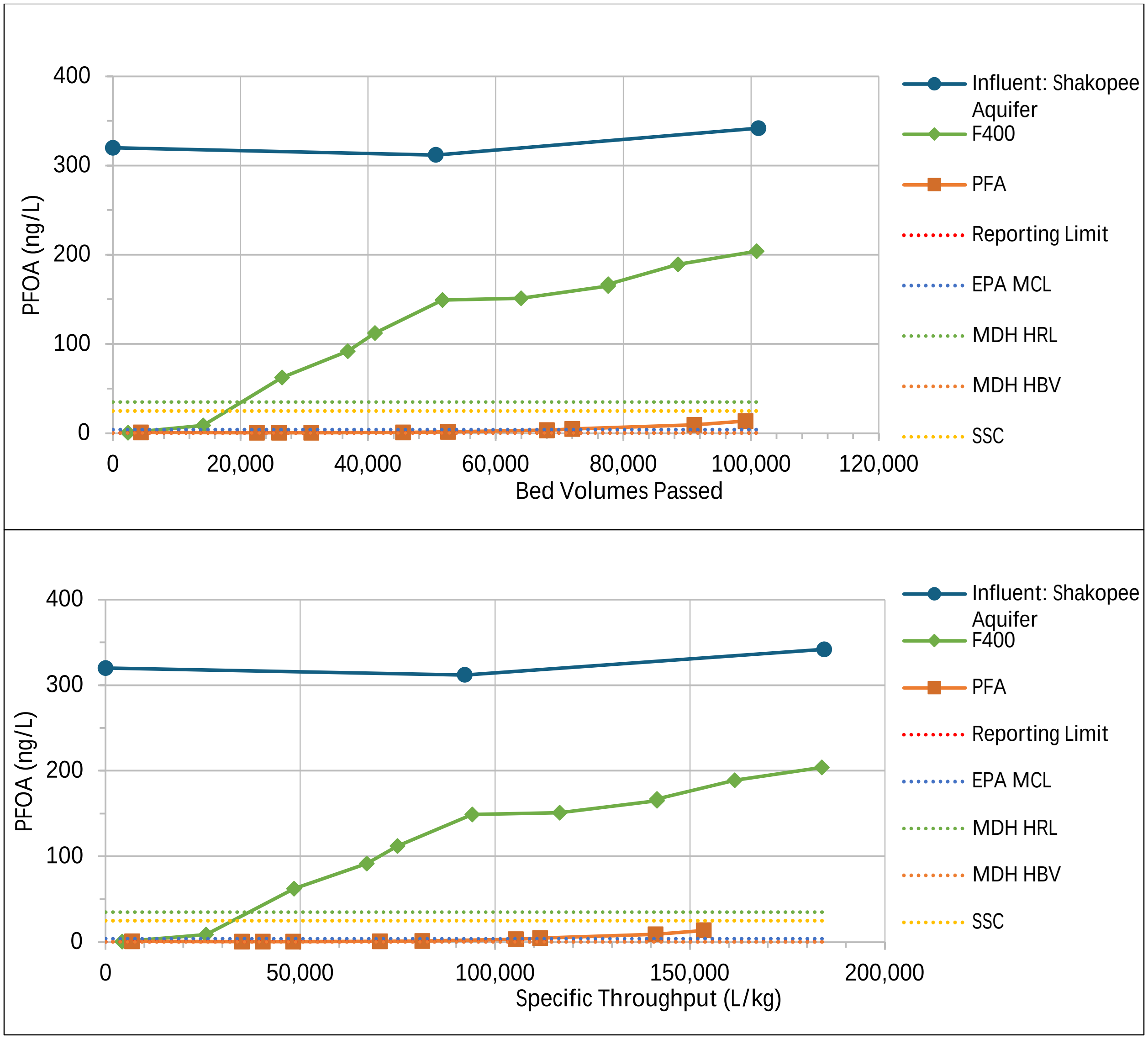


Figure H.76: PFOA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

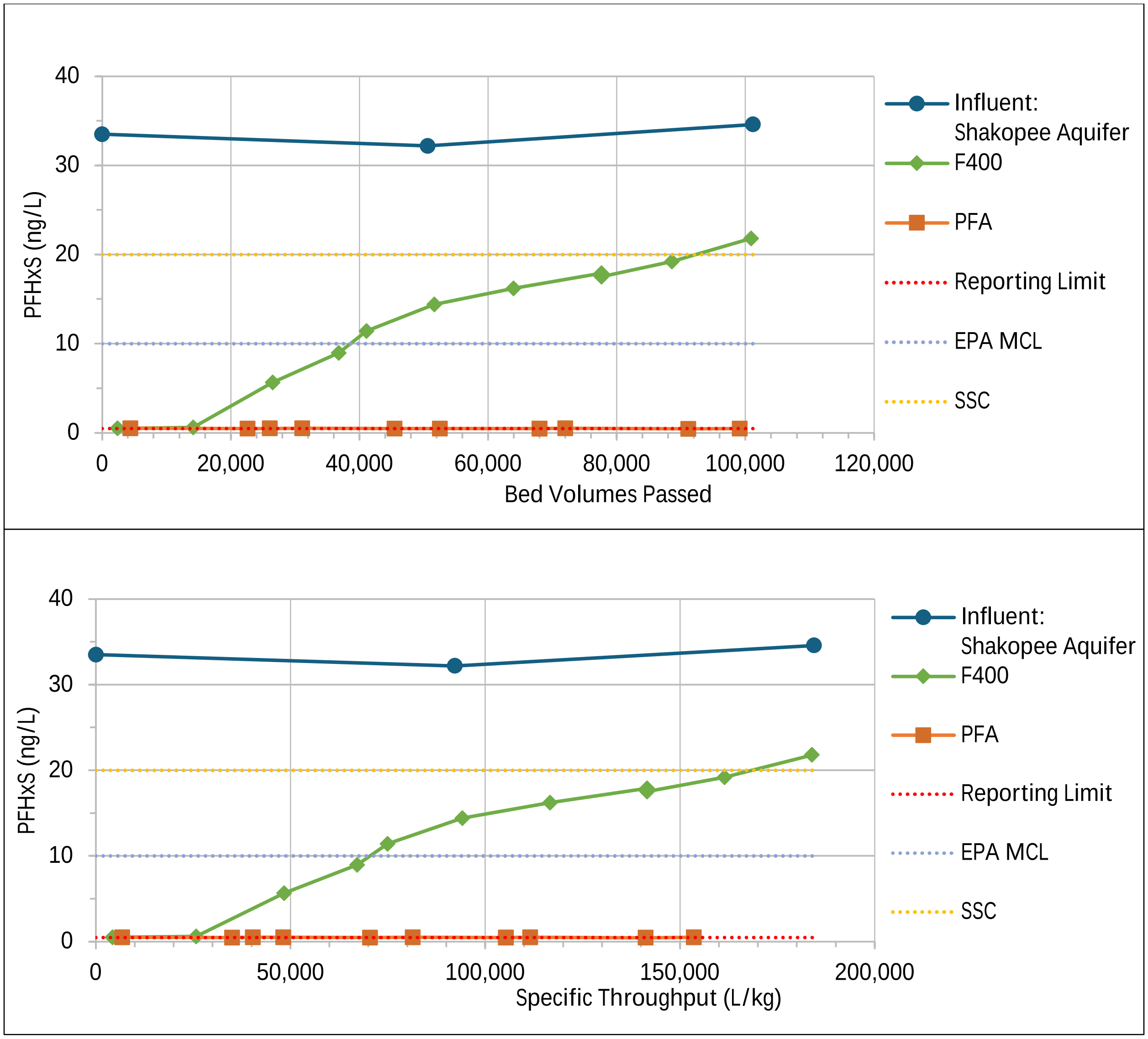


Figure H.77: PFHxS Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

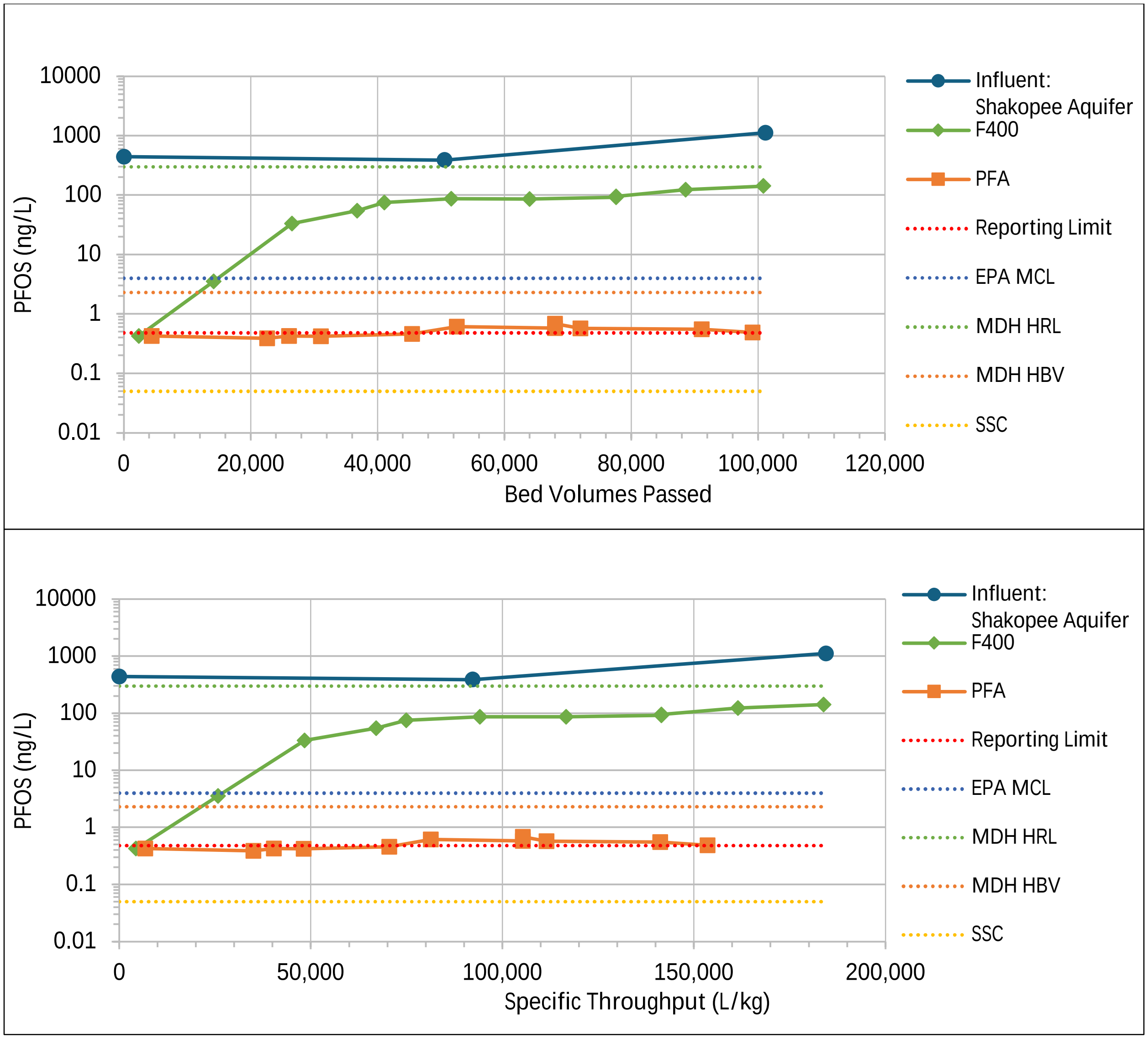


Figure H.78: PFOS Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

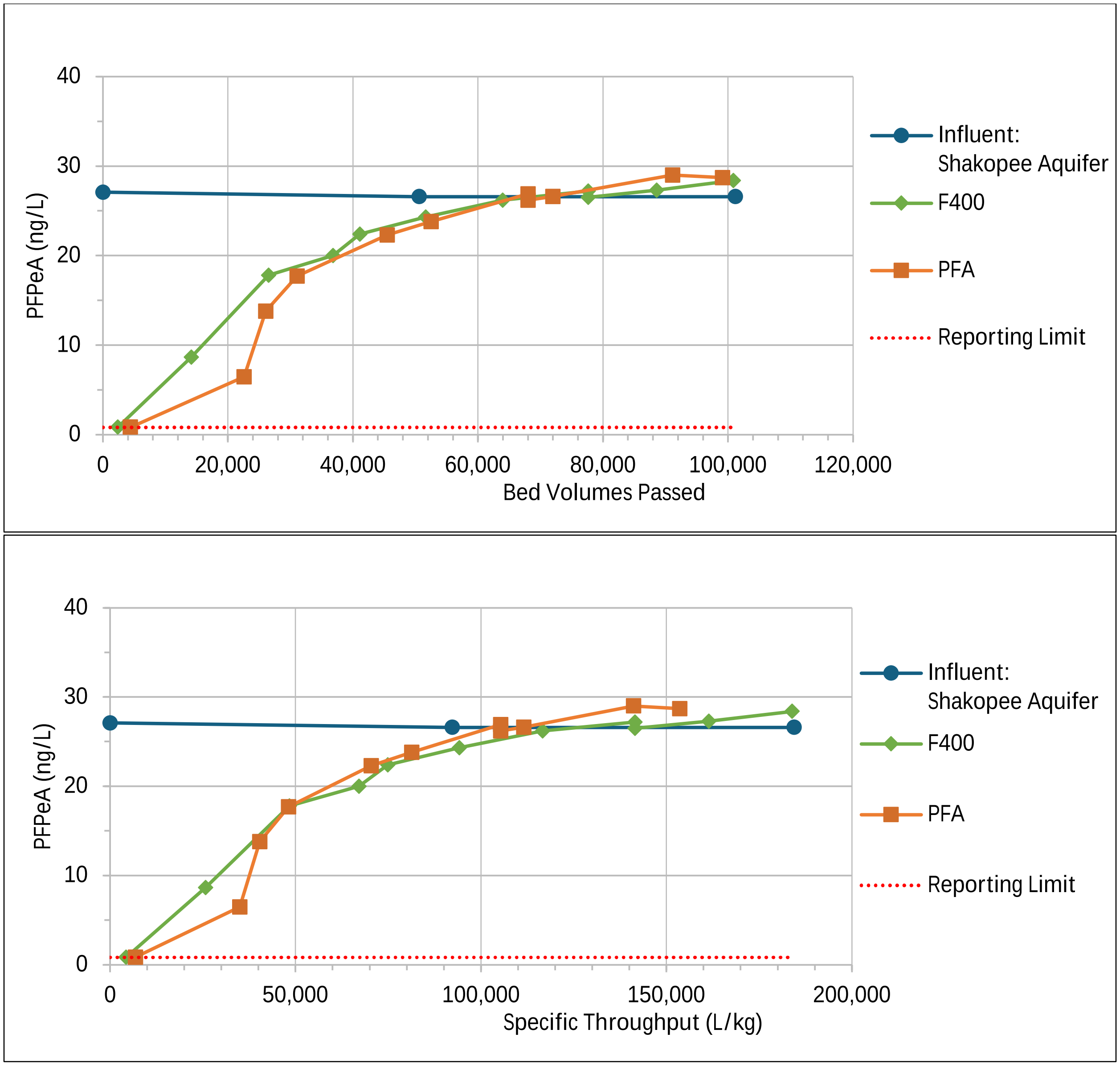


Figure H.79: PFPeA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

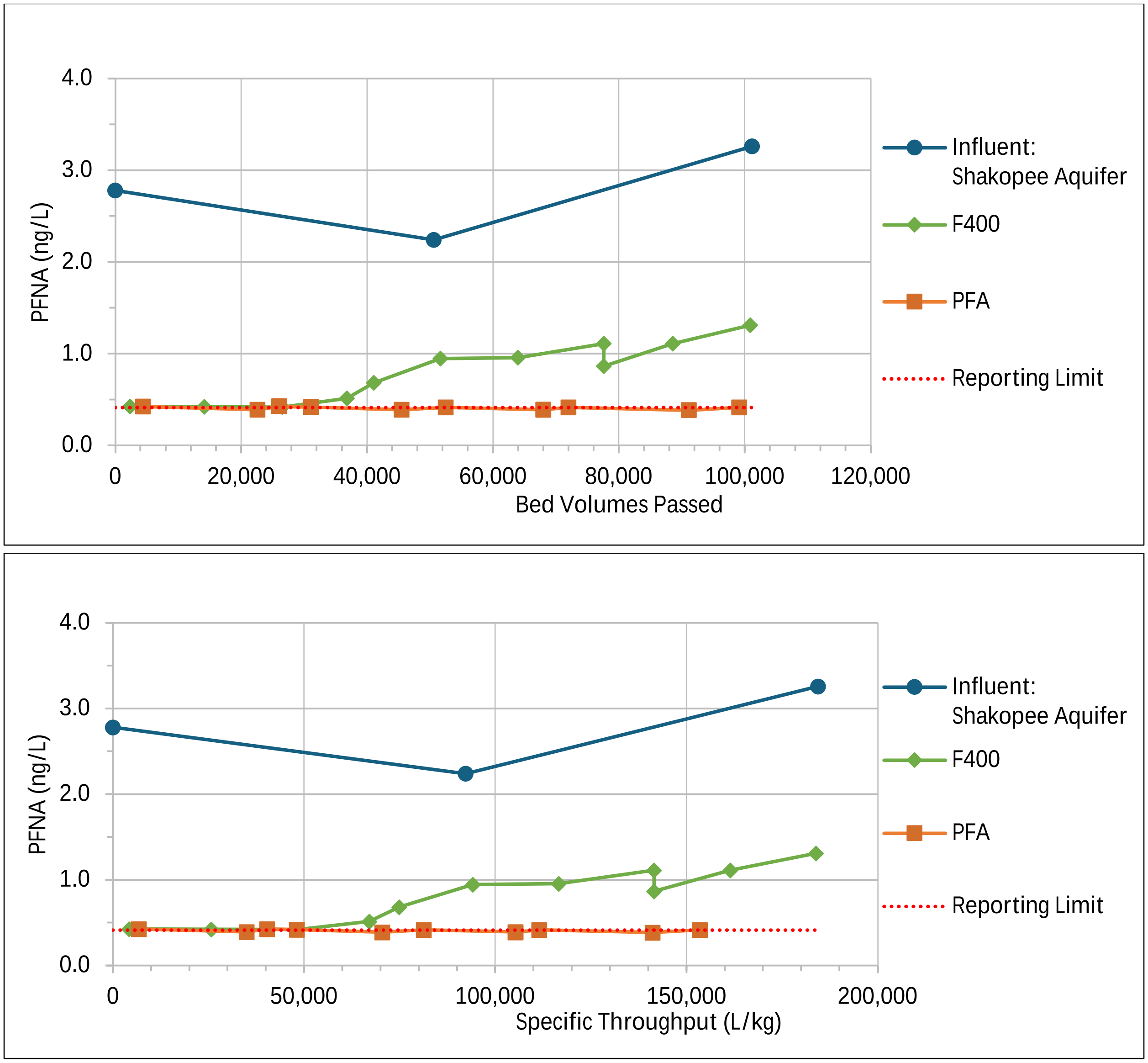


Figure H.80: PFNA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

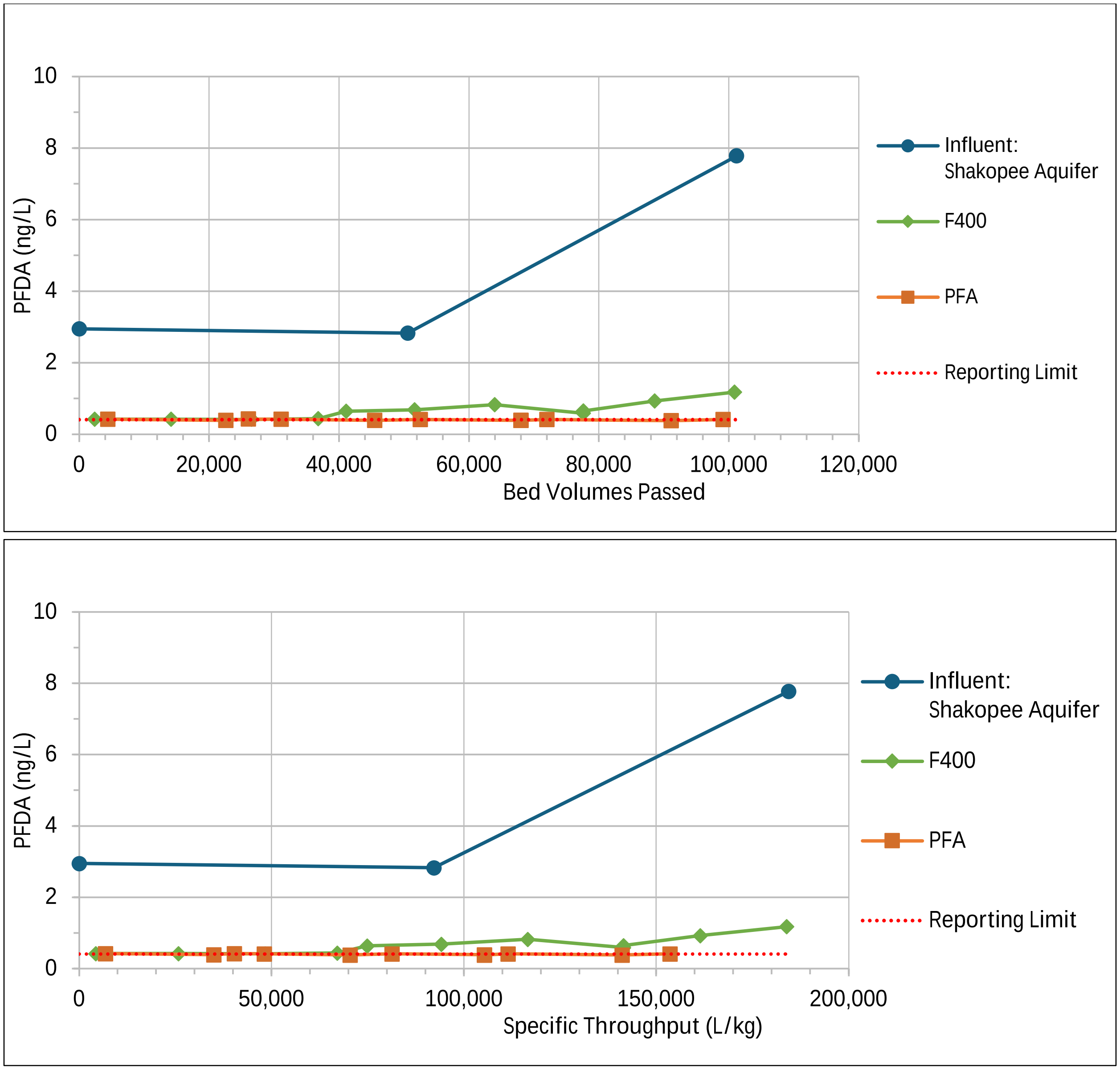


Figure H.81: PFDA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

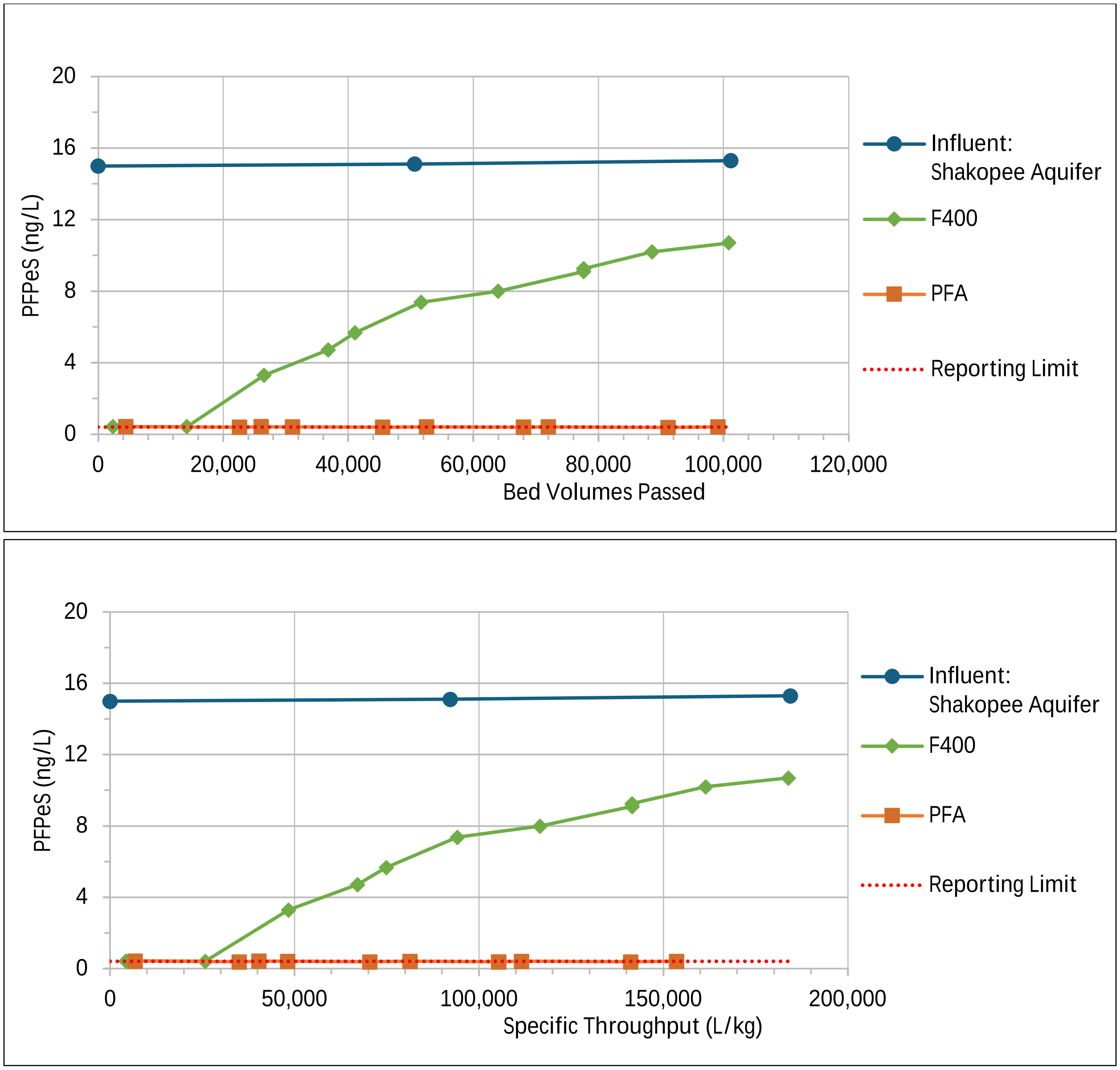


Figure H.82: PFPeS Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

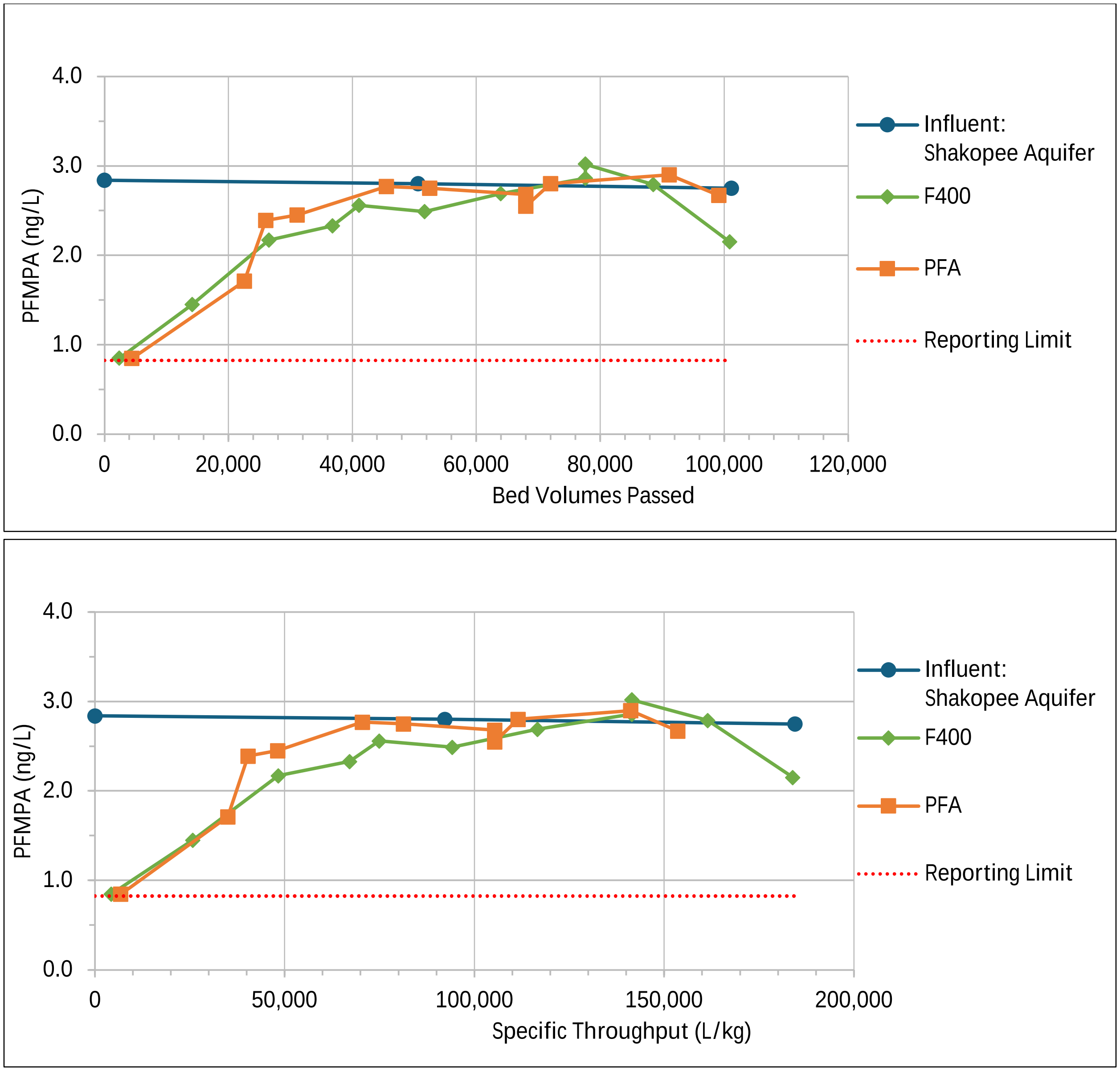


Figure H.83: PFMPA Concentration vs Bed Volumes & Specific Throughput for Shakopee Aquifer.

H7.3 Washington County Landfill Plots for Detected Compounds

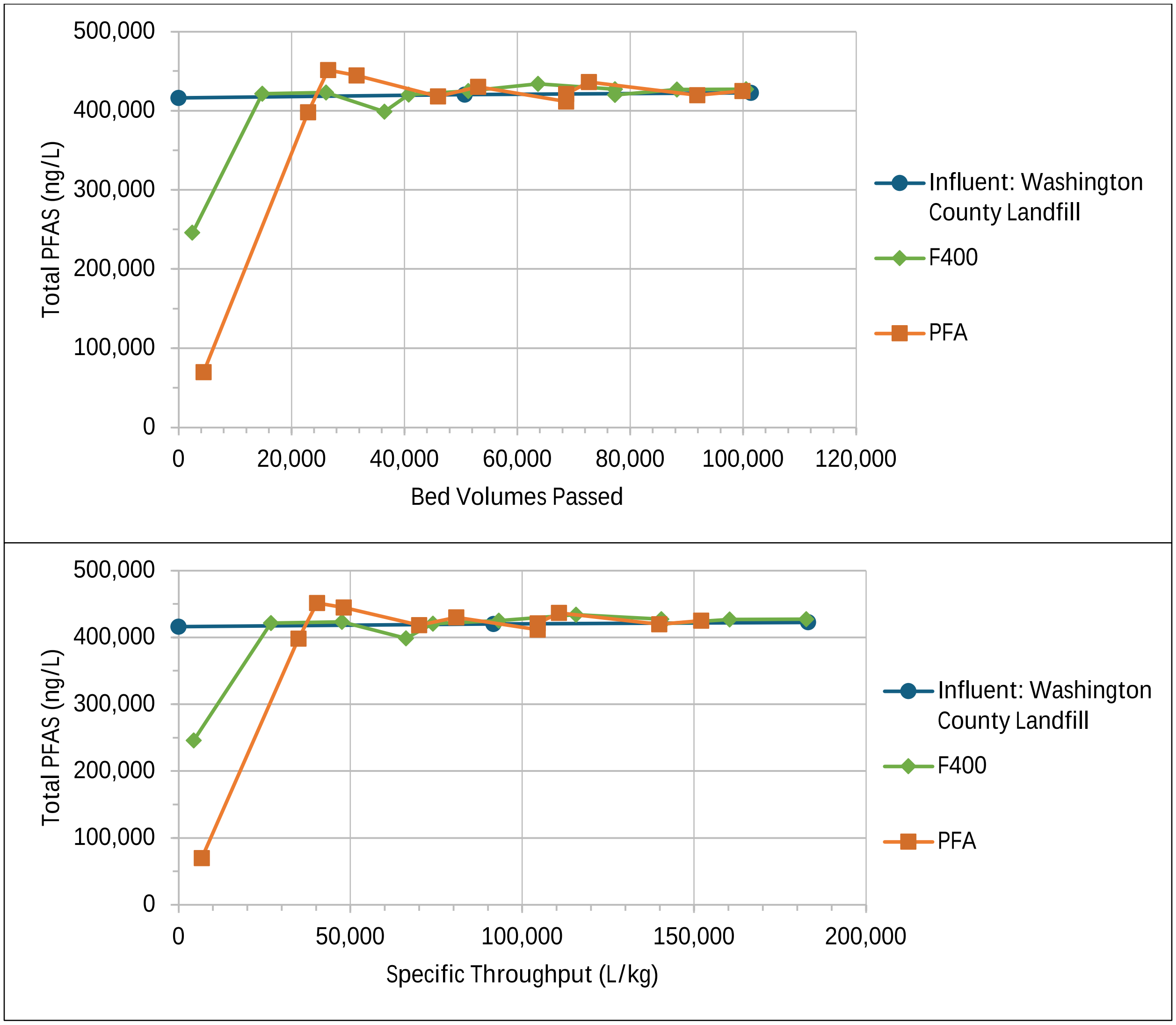


Figure H.84: Total PFAS Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

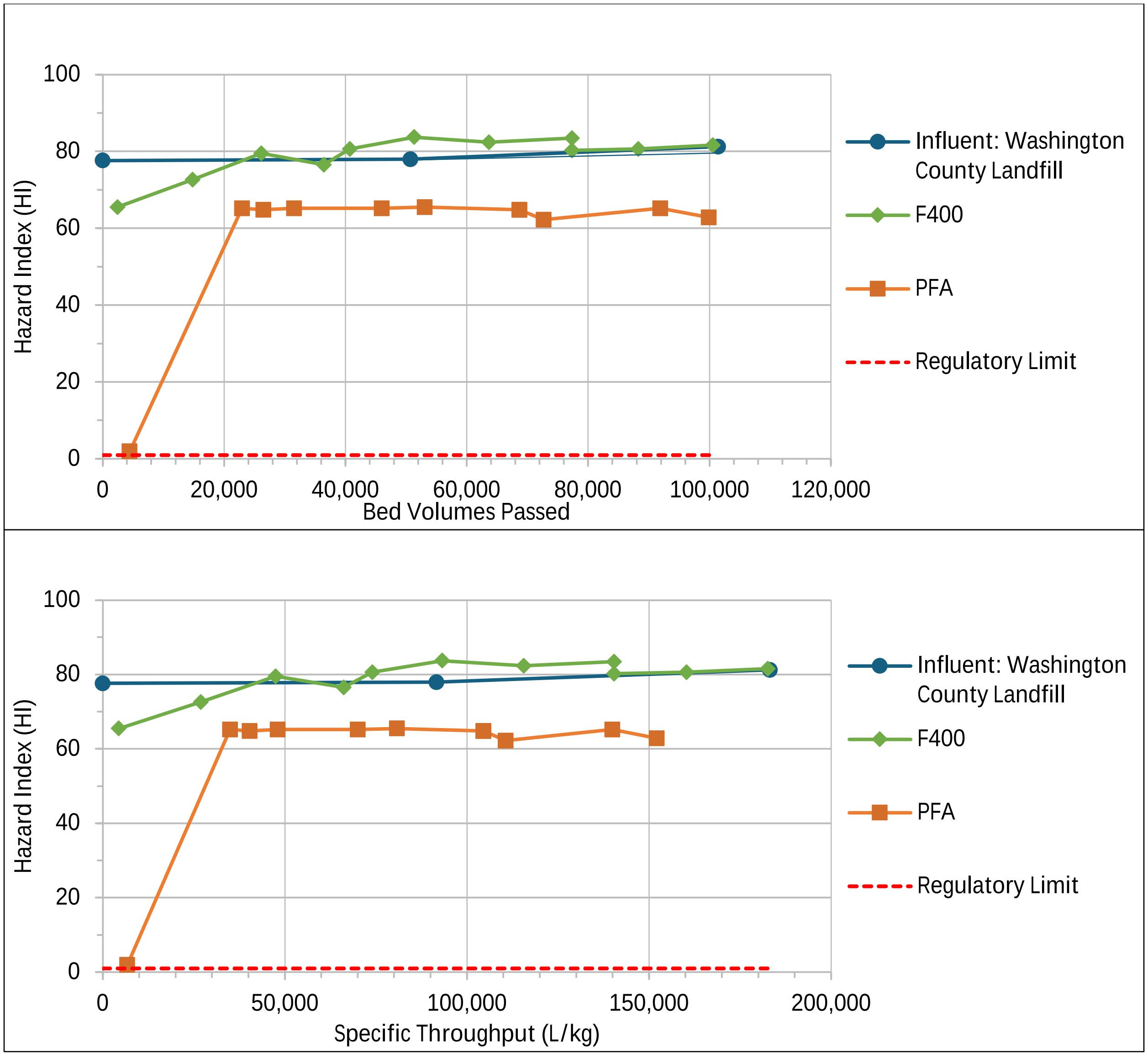


Figure H.85: Hazard Index vs Bed Volumes & Specific Throughput for Washington County Landfill.

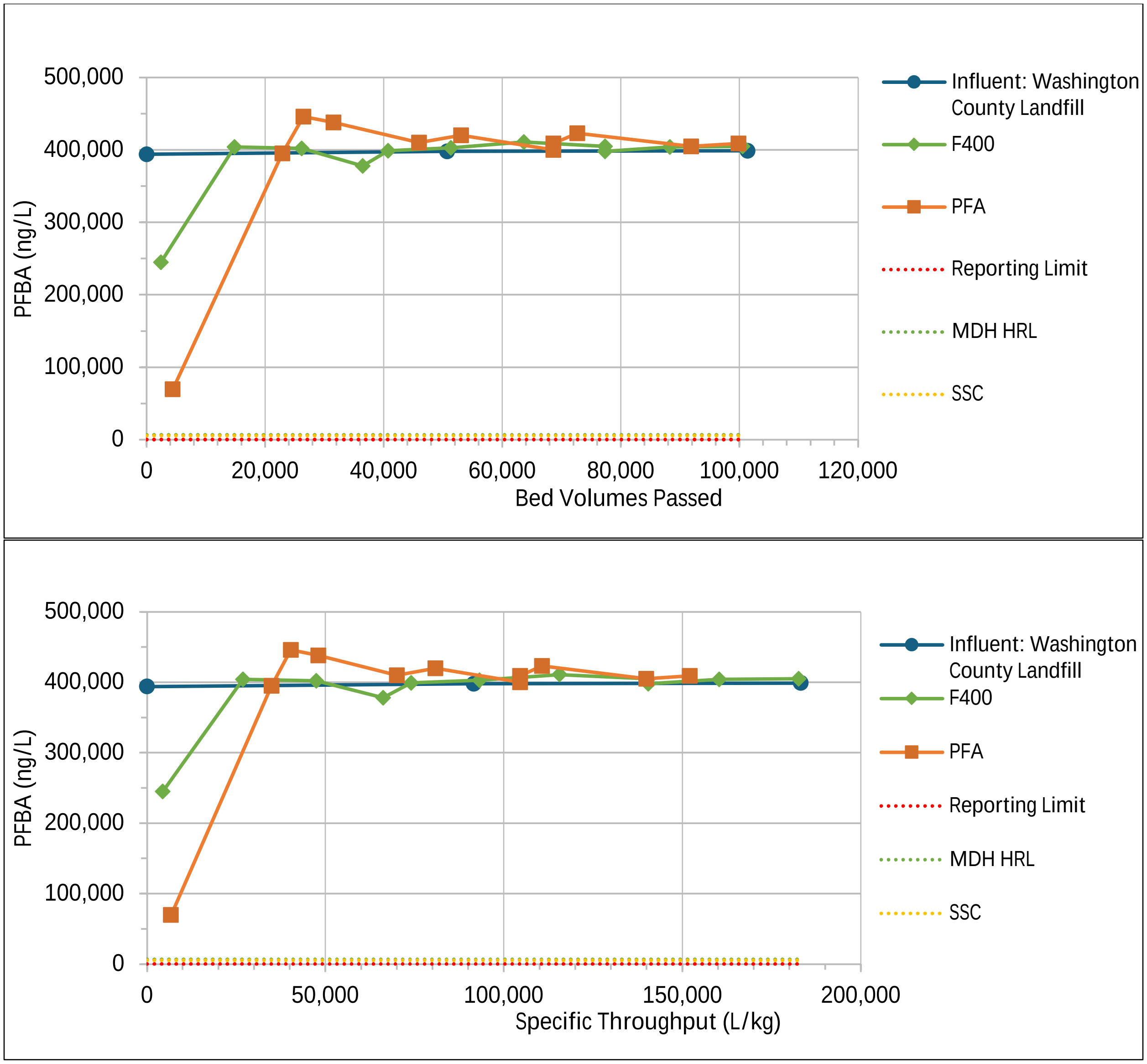
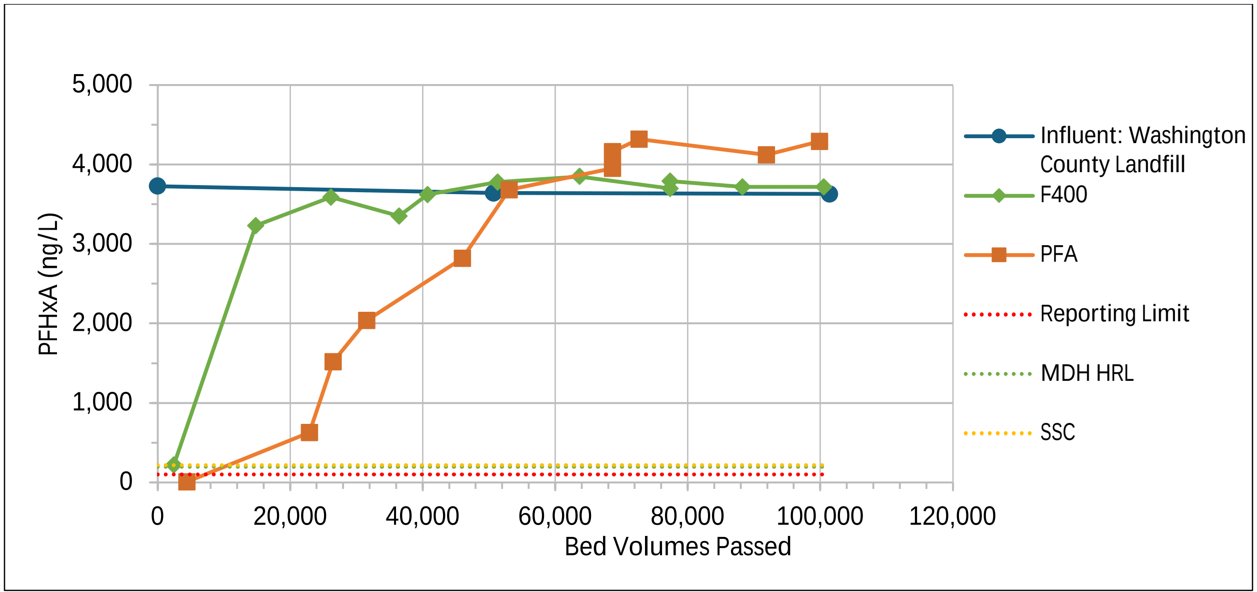


Figure H.86: PFBA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.



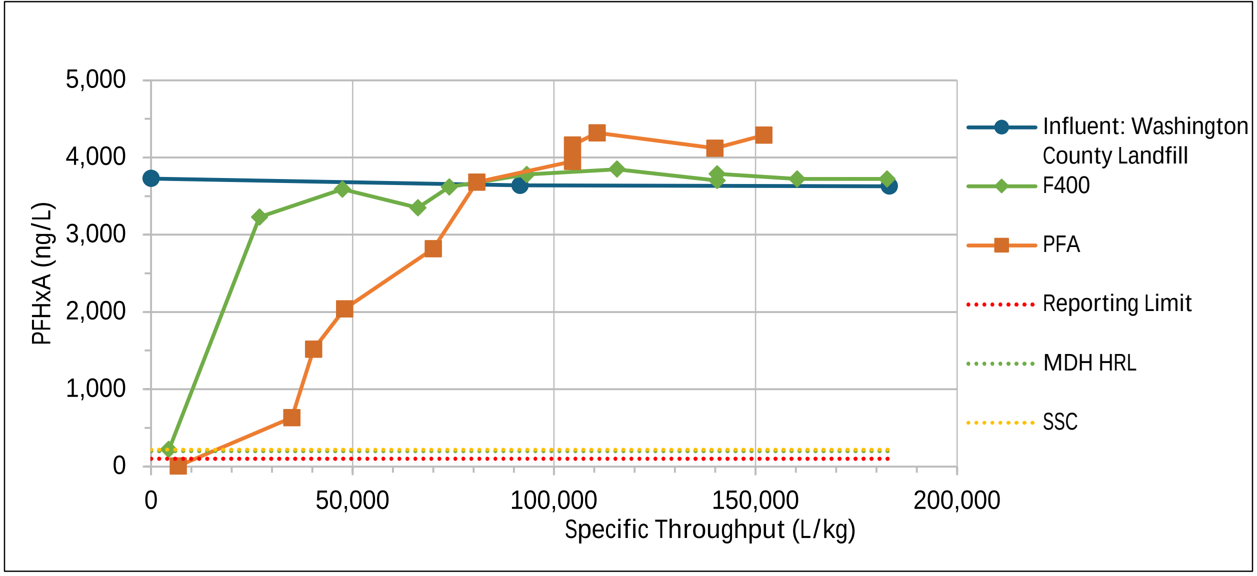
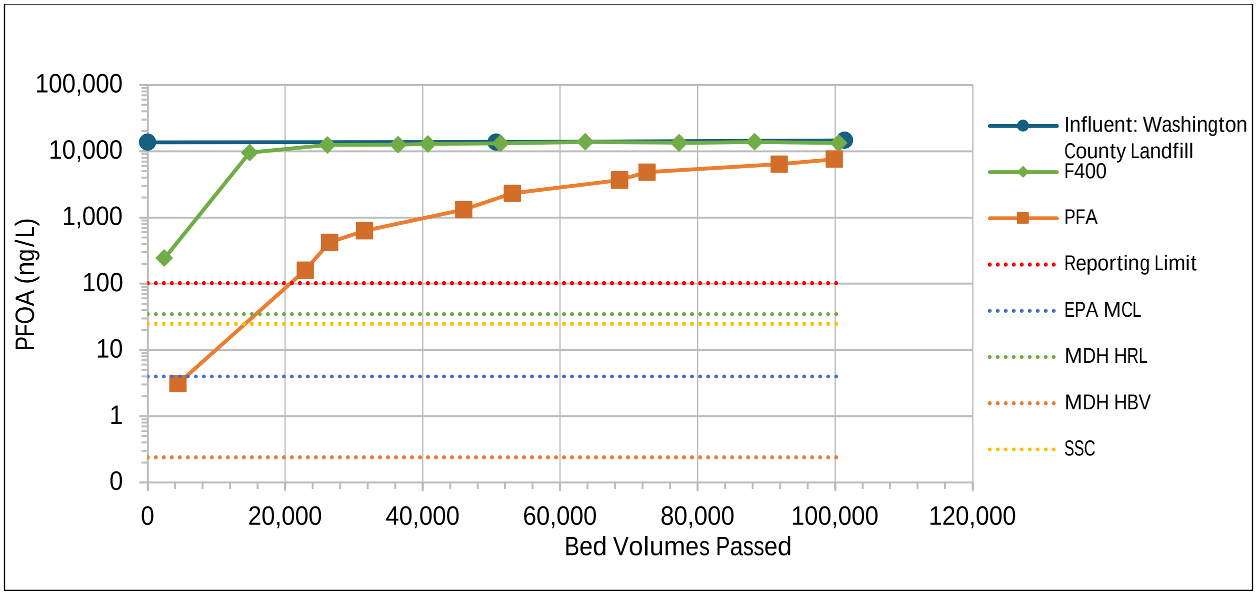


Figure H.87: PFHxA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.



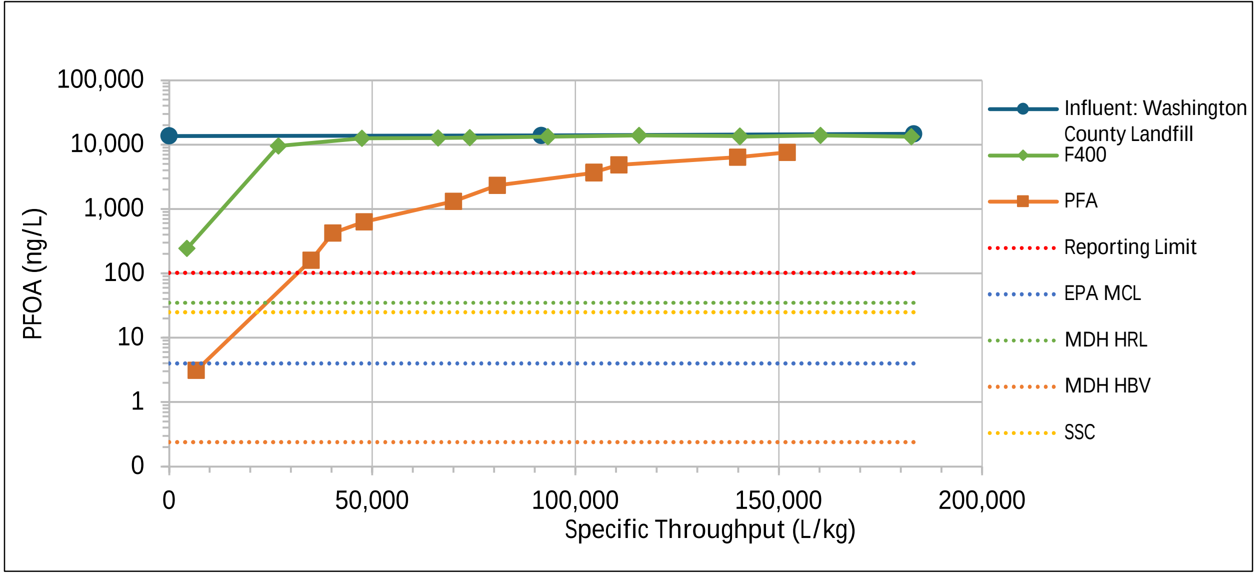


Figure H.88: PFOA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

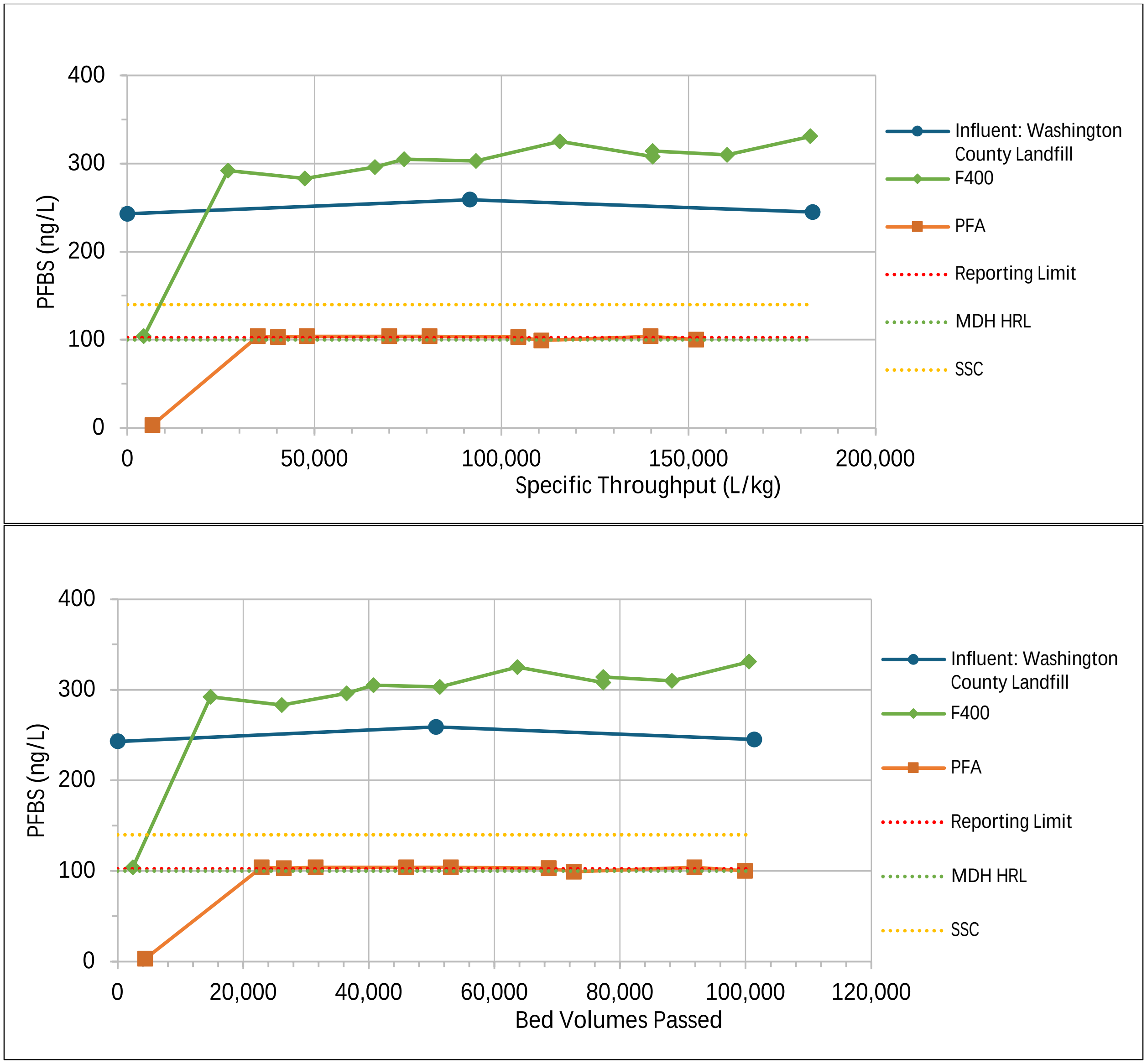


Figure H.89: PFBS Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

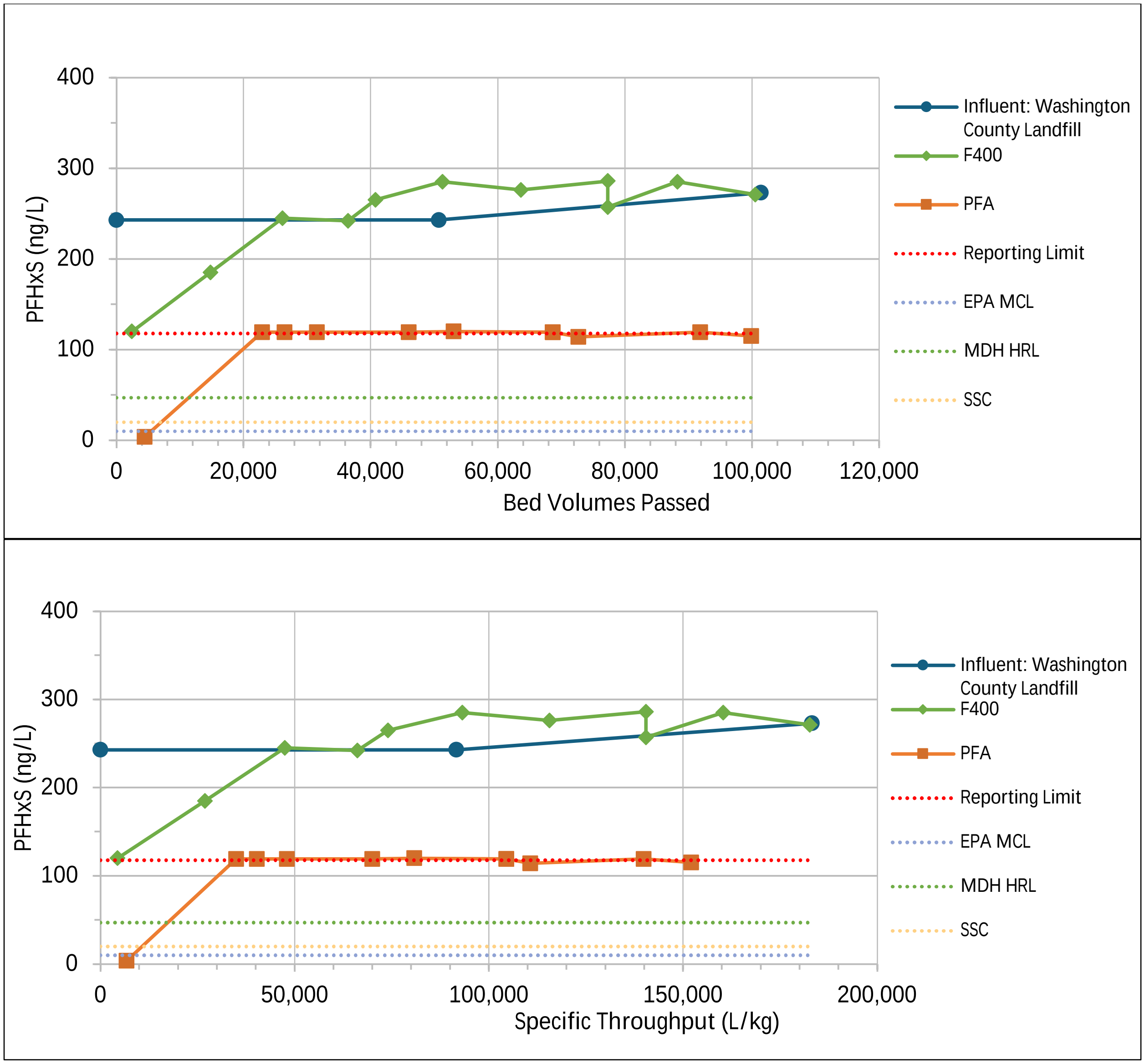


Figure H.90: PFHxS Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

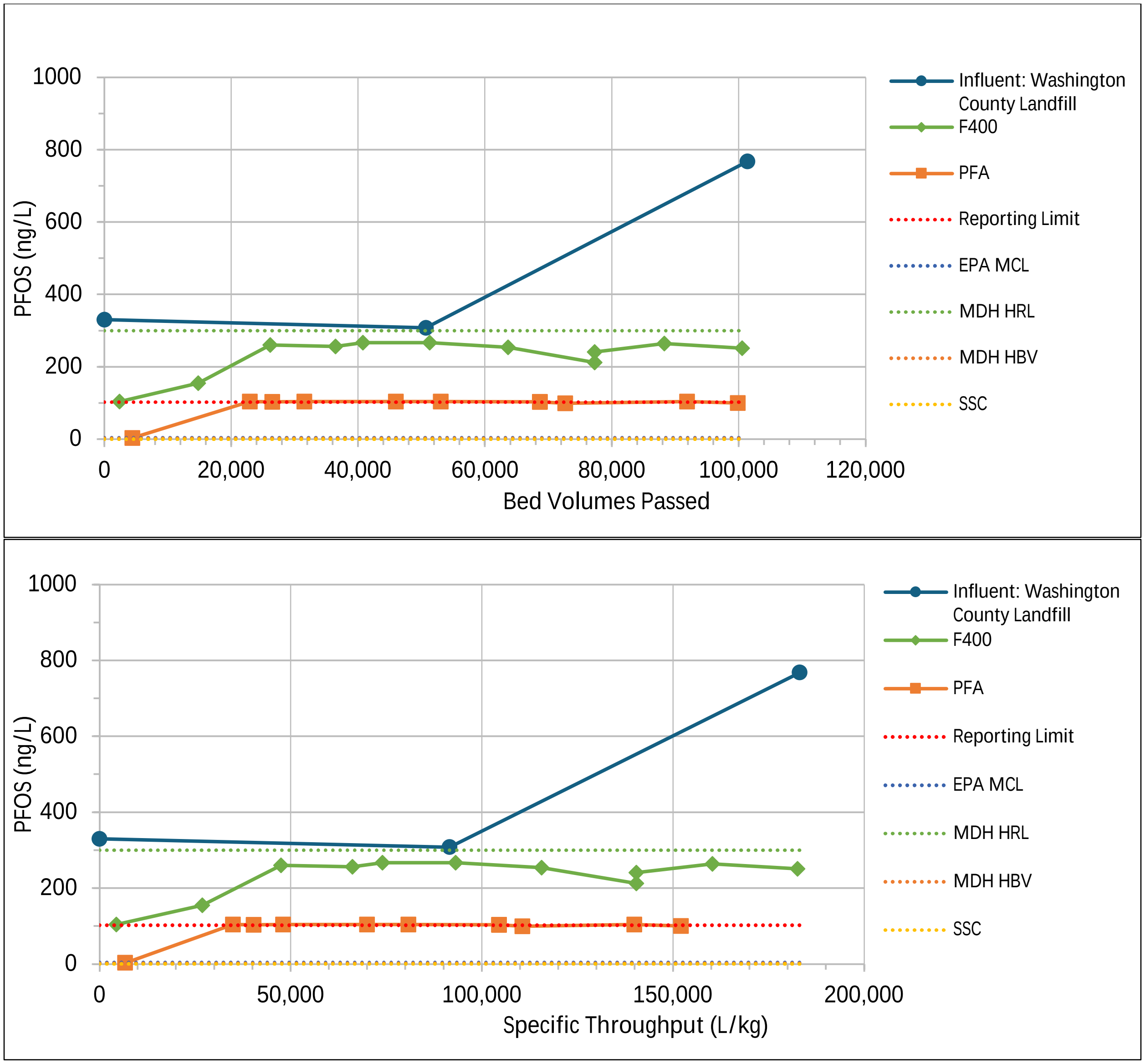


Figure H.91: PFOS Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

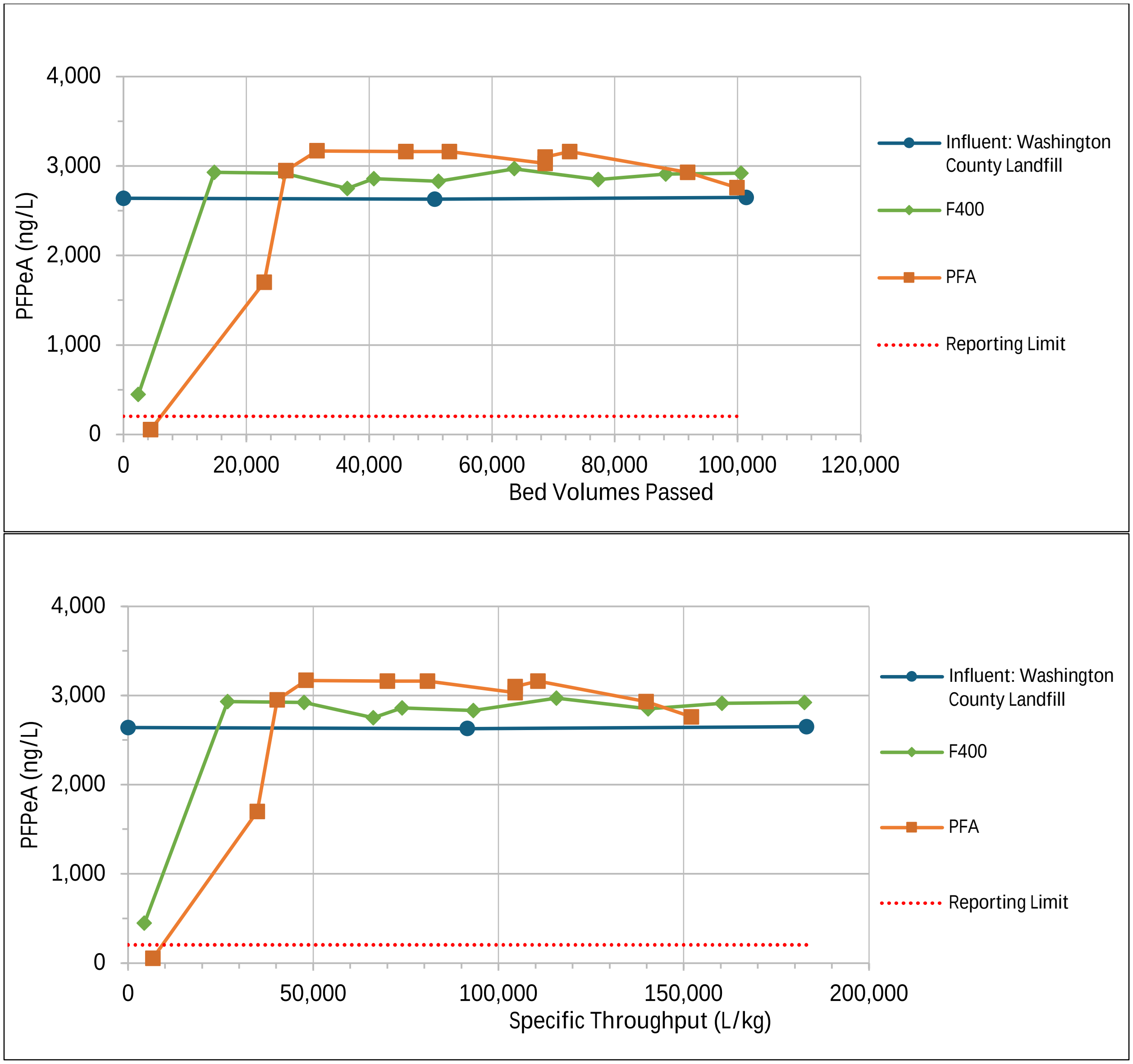


Figure H.92: PFPeA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

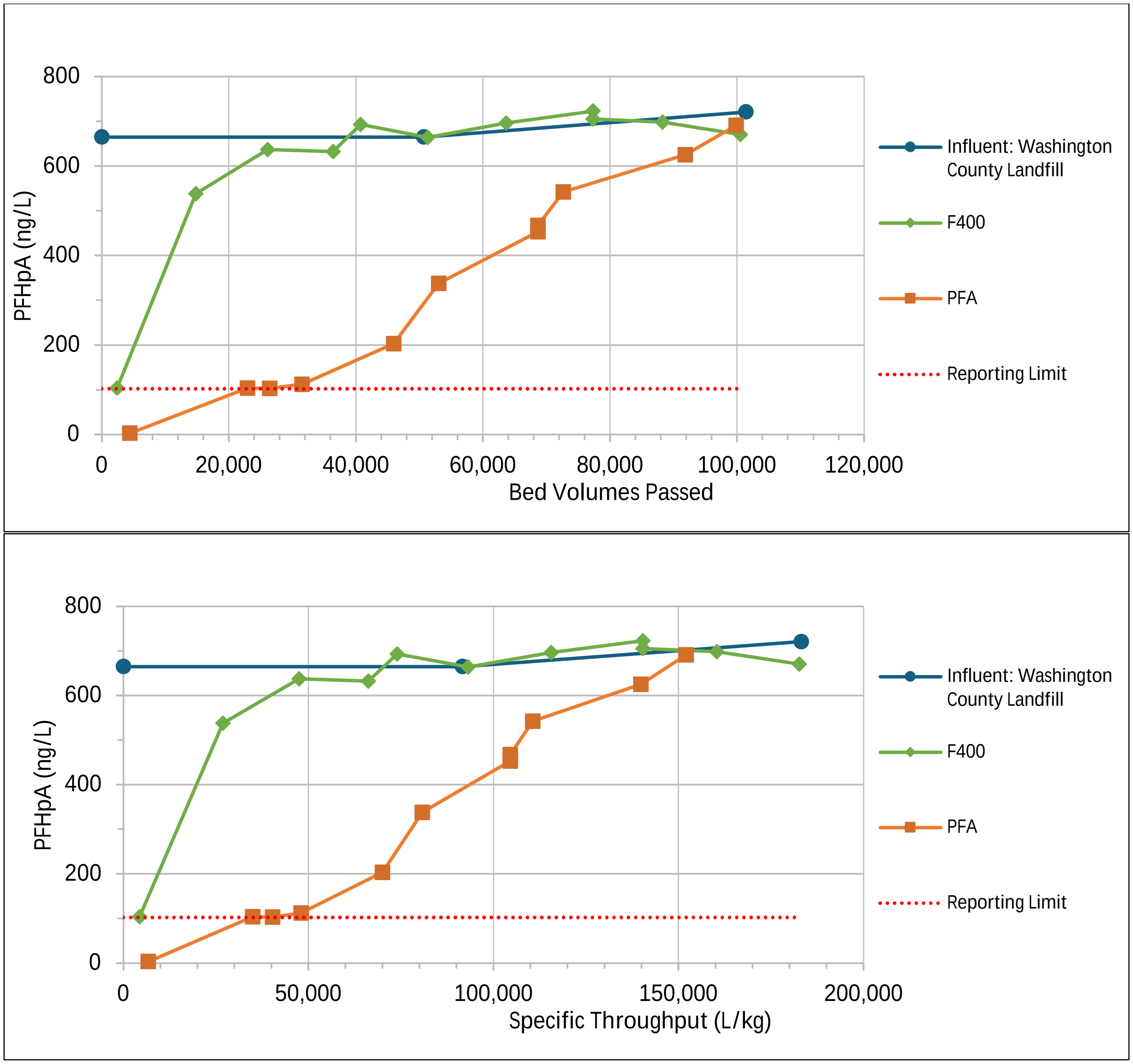


Figure H.93: PFHpA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

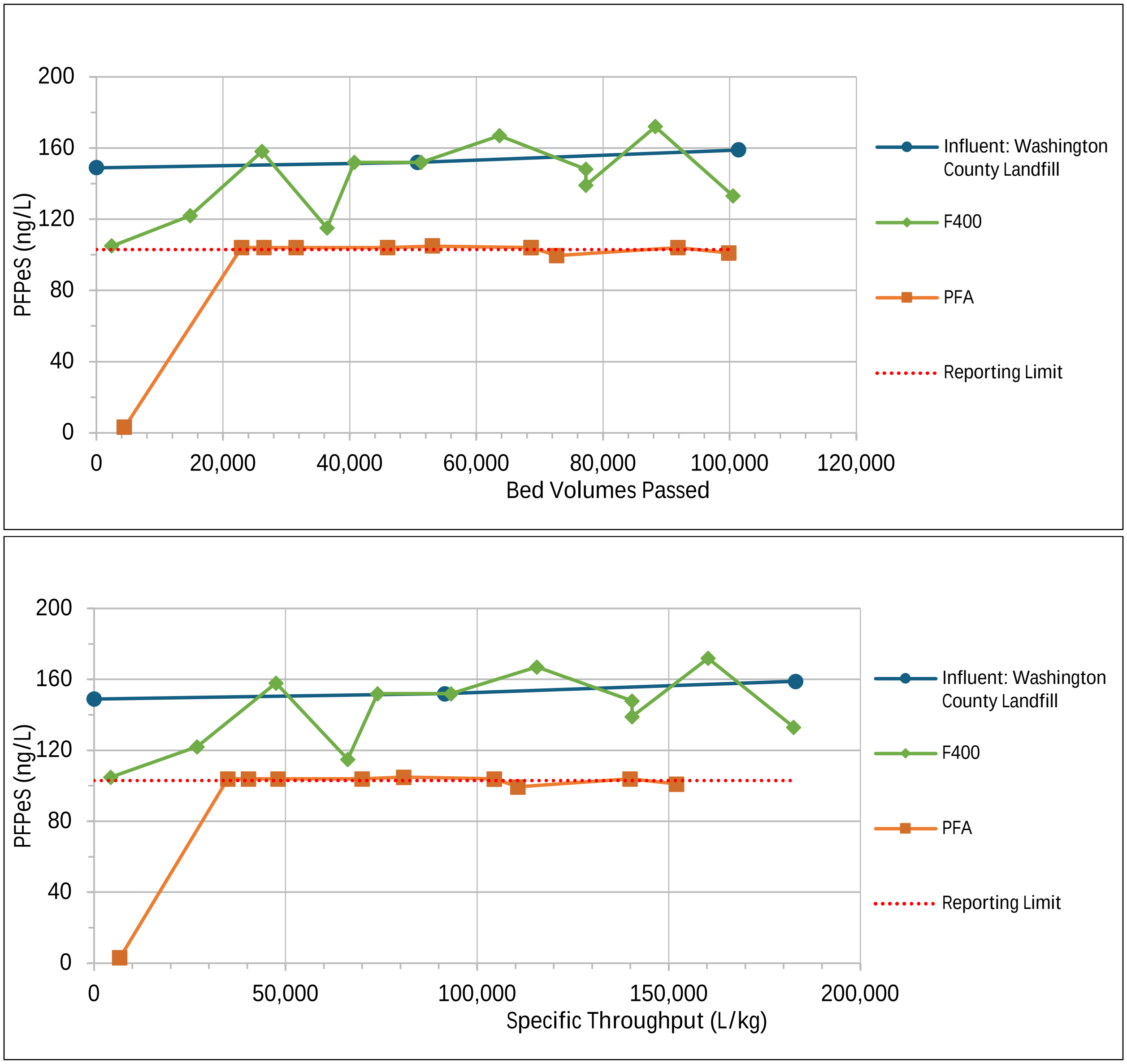


Figure H.94: PFPeS Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

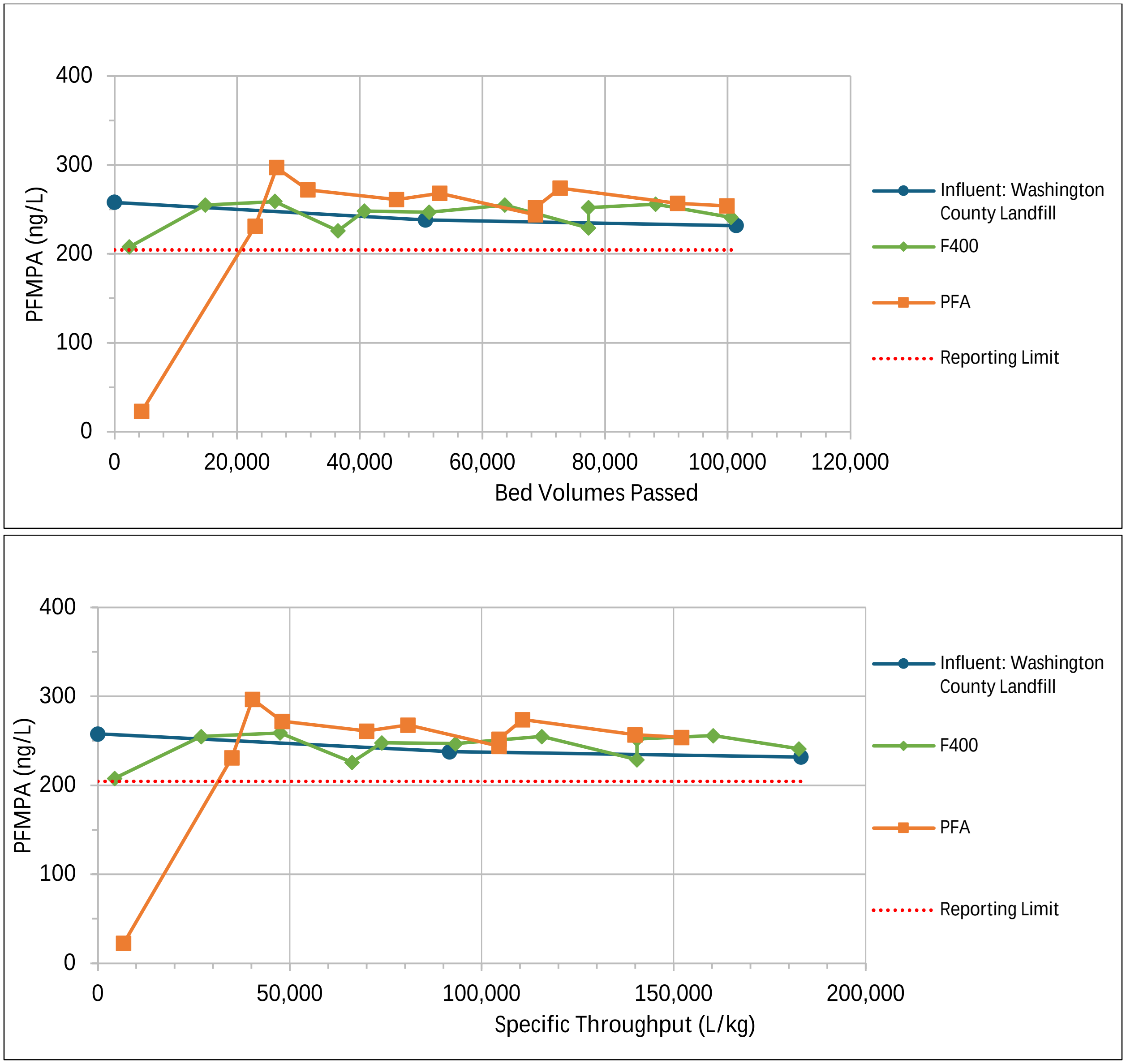


Figure H.95: PFMPA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

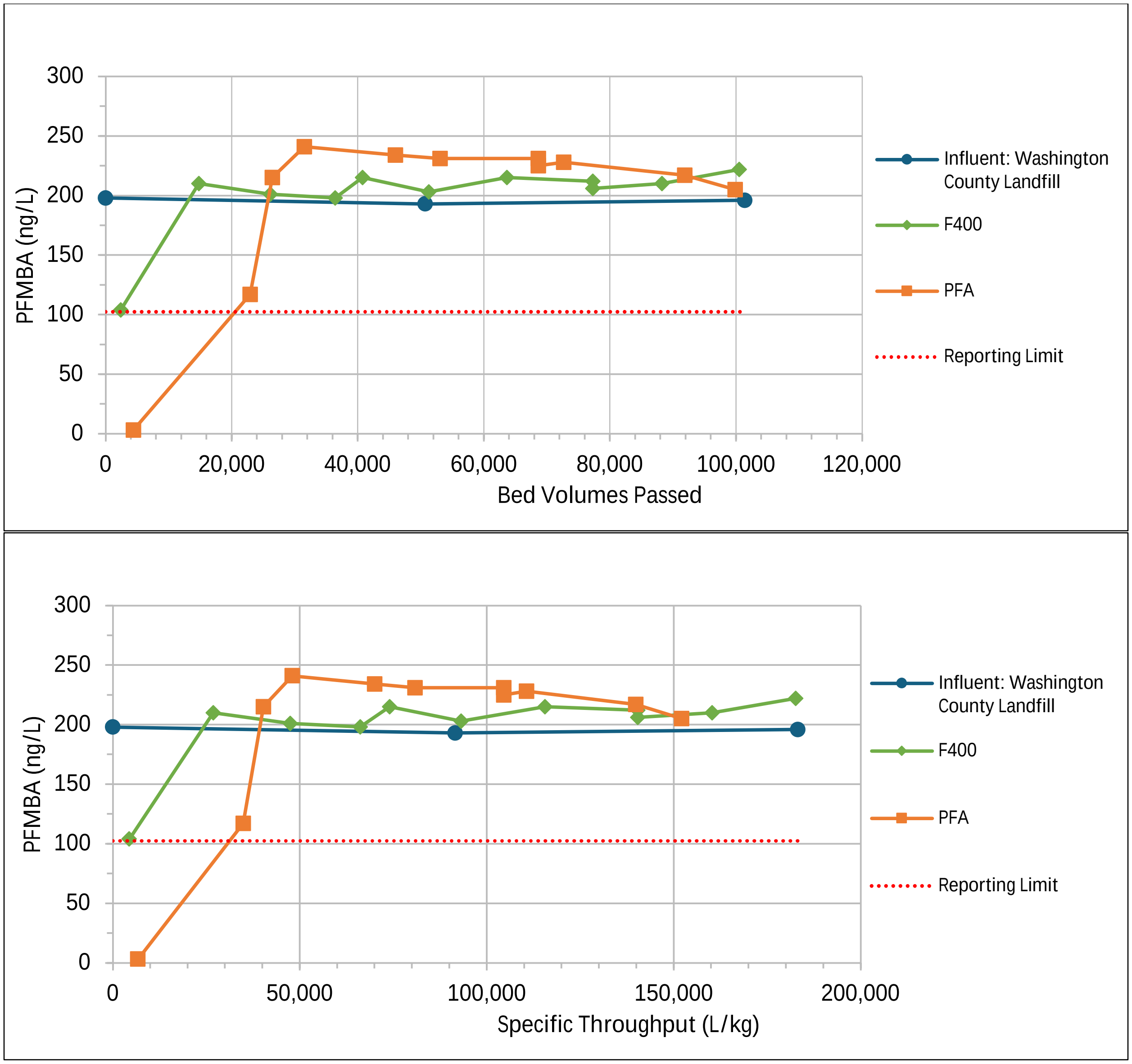


Figure H.96: PFMBA Concentration vs Bed Volumes & Specific Throughput for Washington County Landfill.

H7.4 SAFF® Treated Groundwaters Plots for Detected Compounds

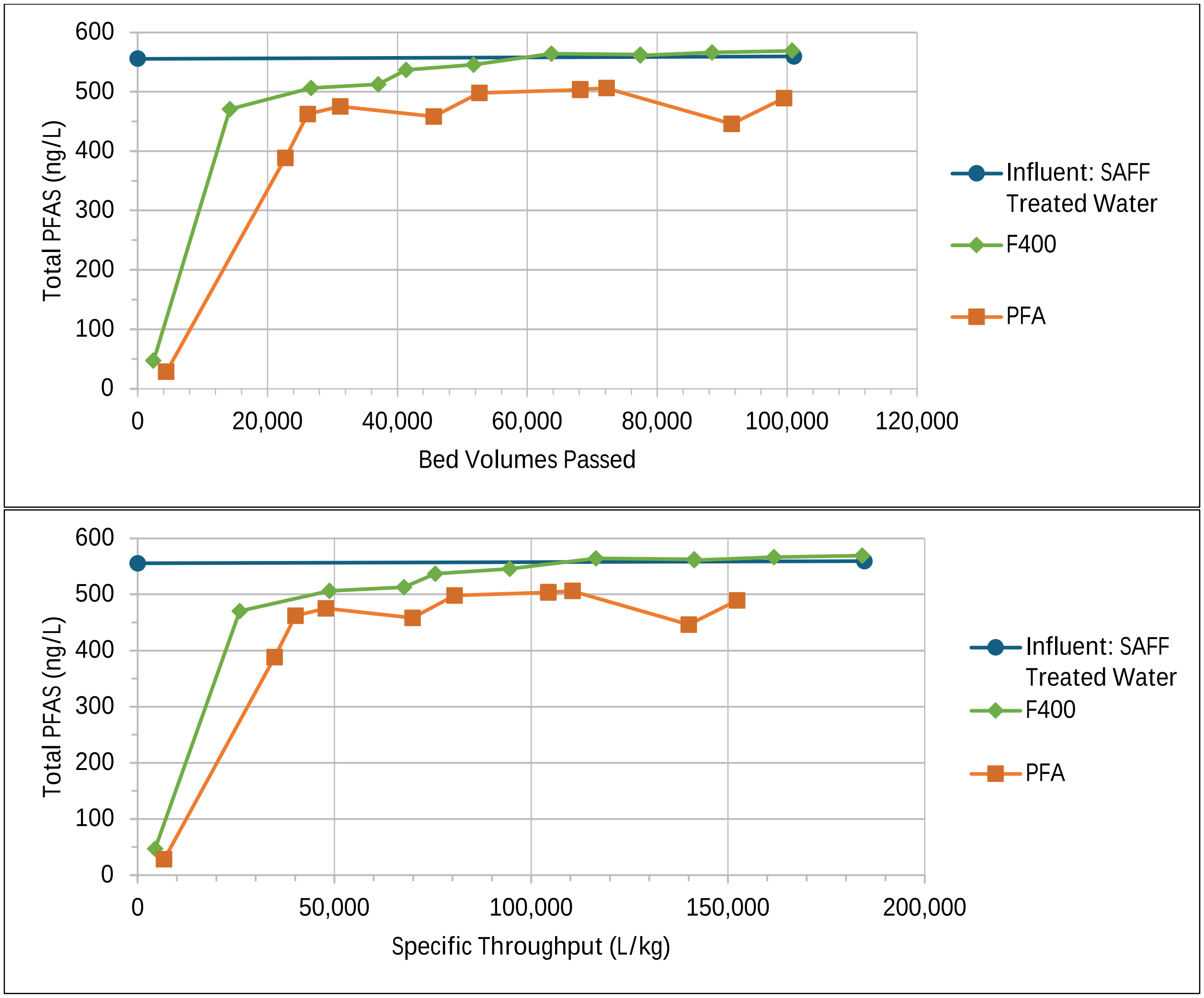


Figure H.97: Total PFAS Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

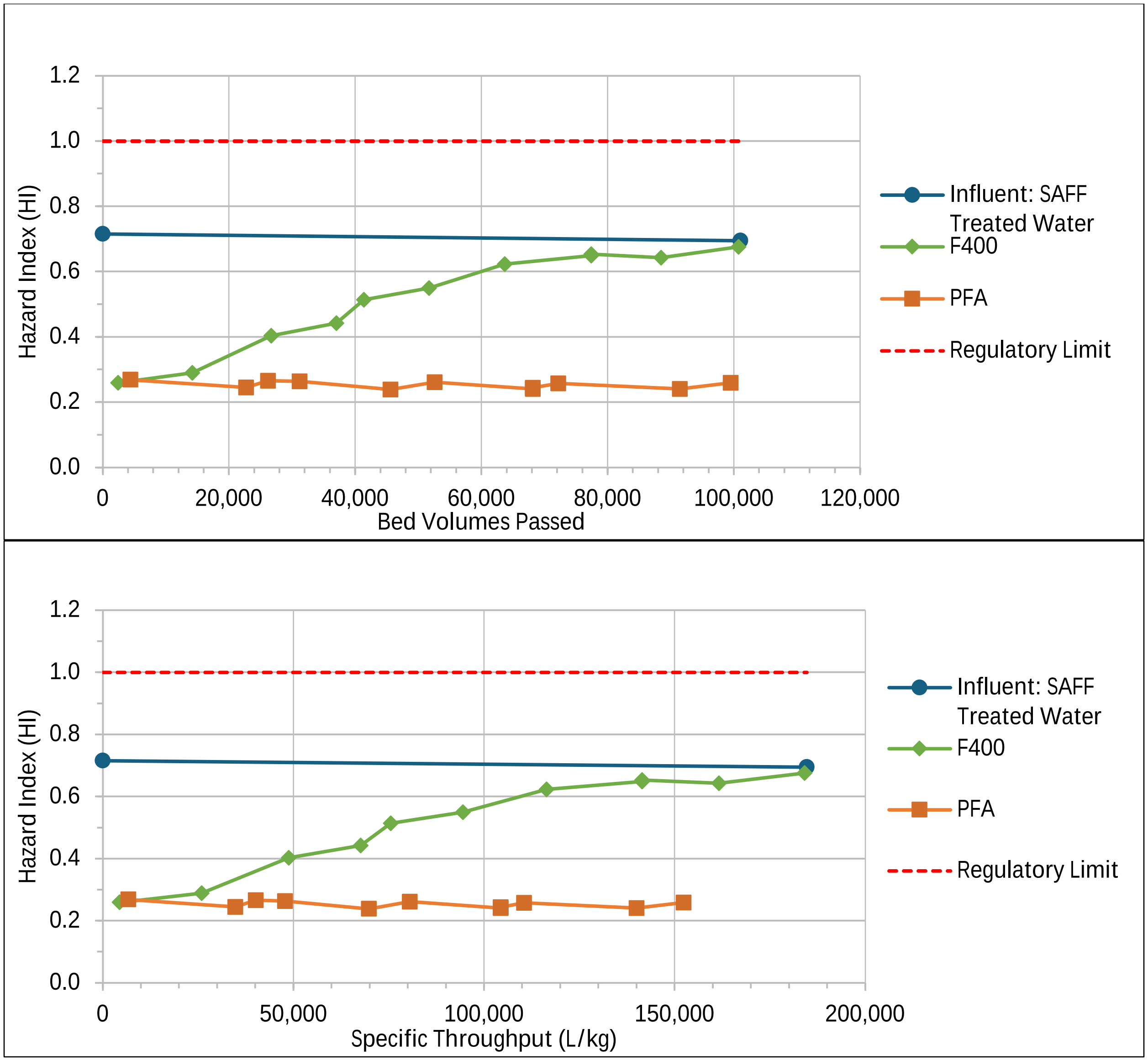


Figure H.98: Hazard Index vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

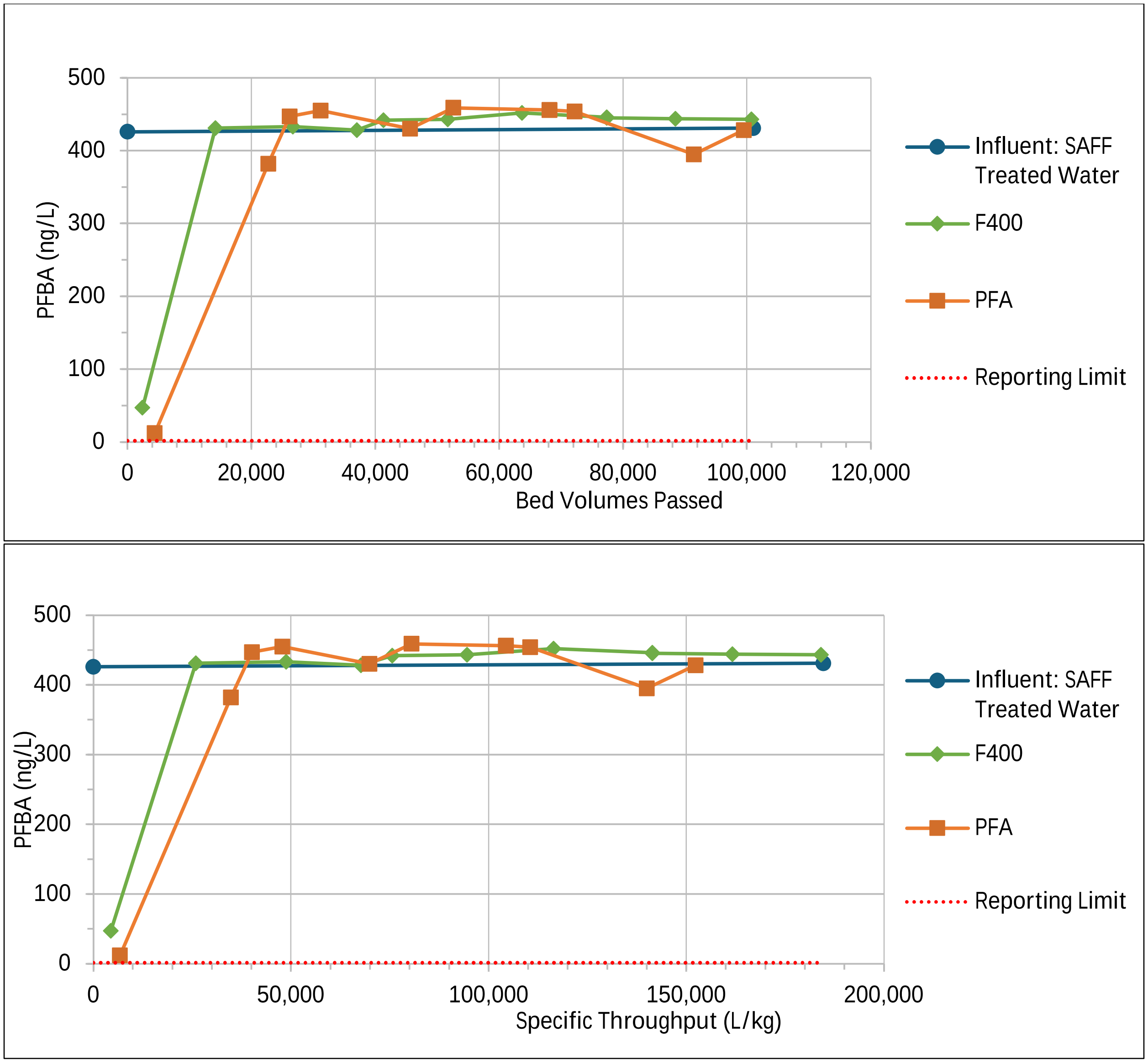


Figure H.99: PFBA Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

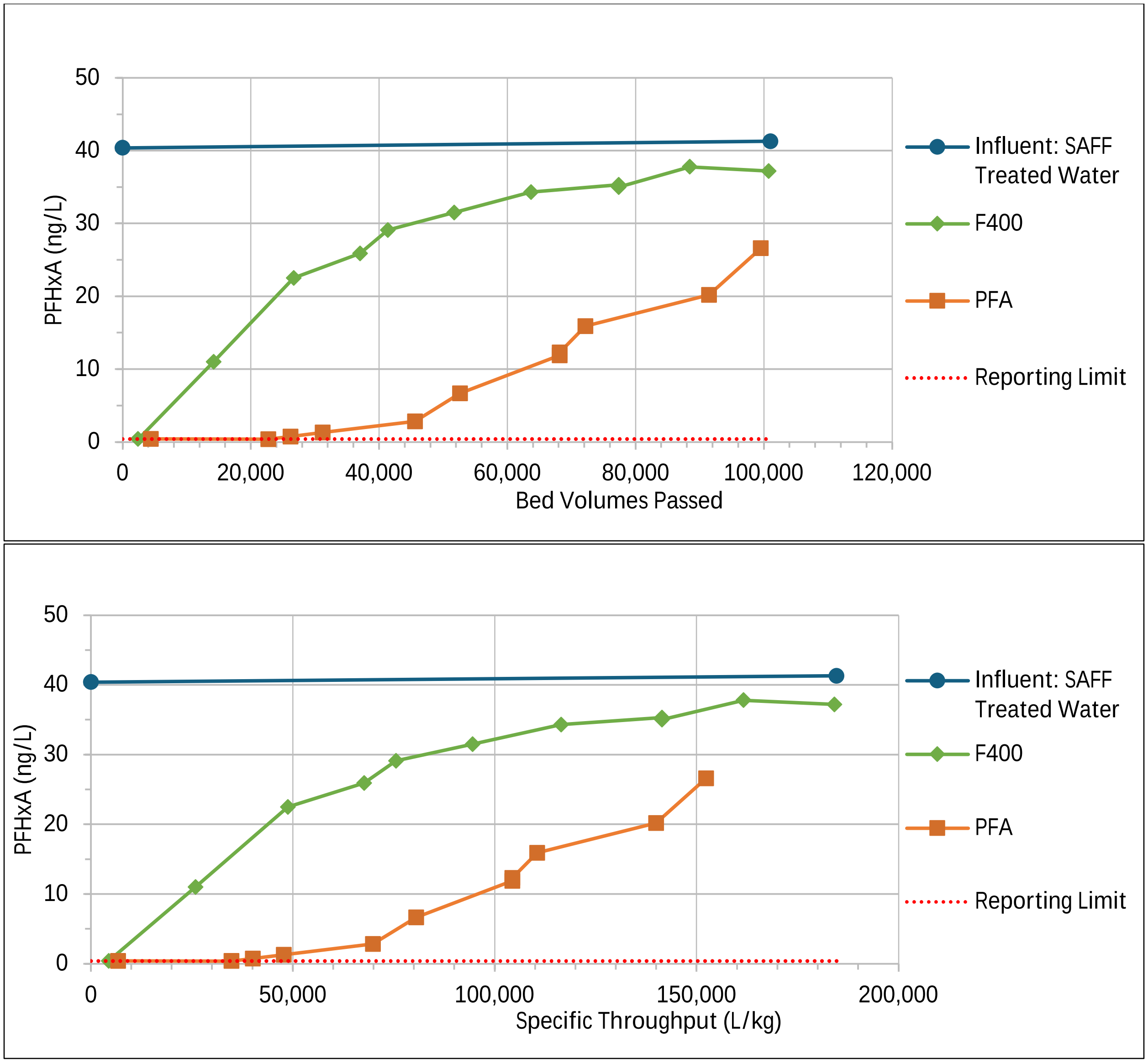


Figure H.100: PFHxA Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

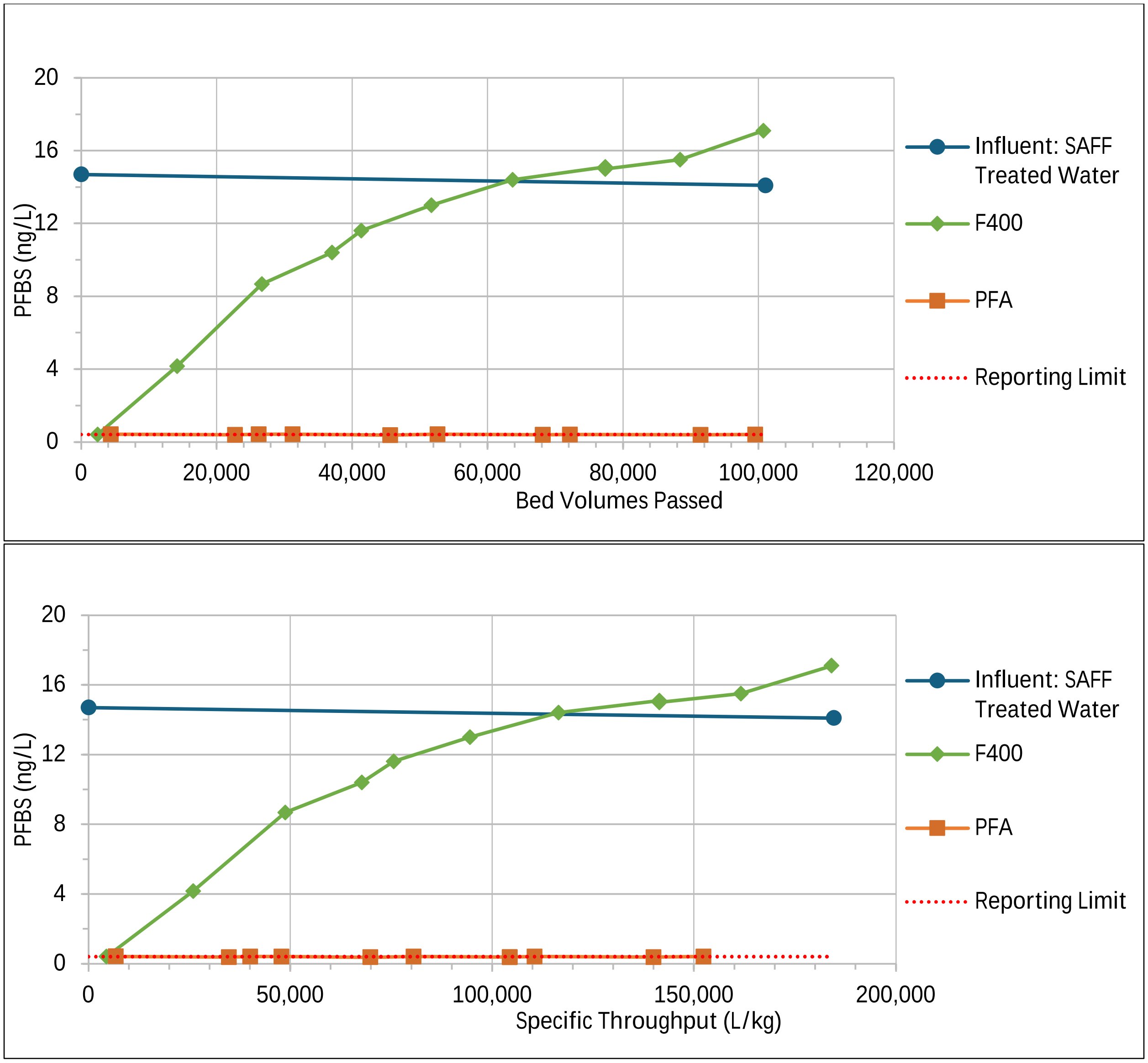


Figure H.101: PFBS Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

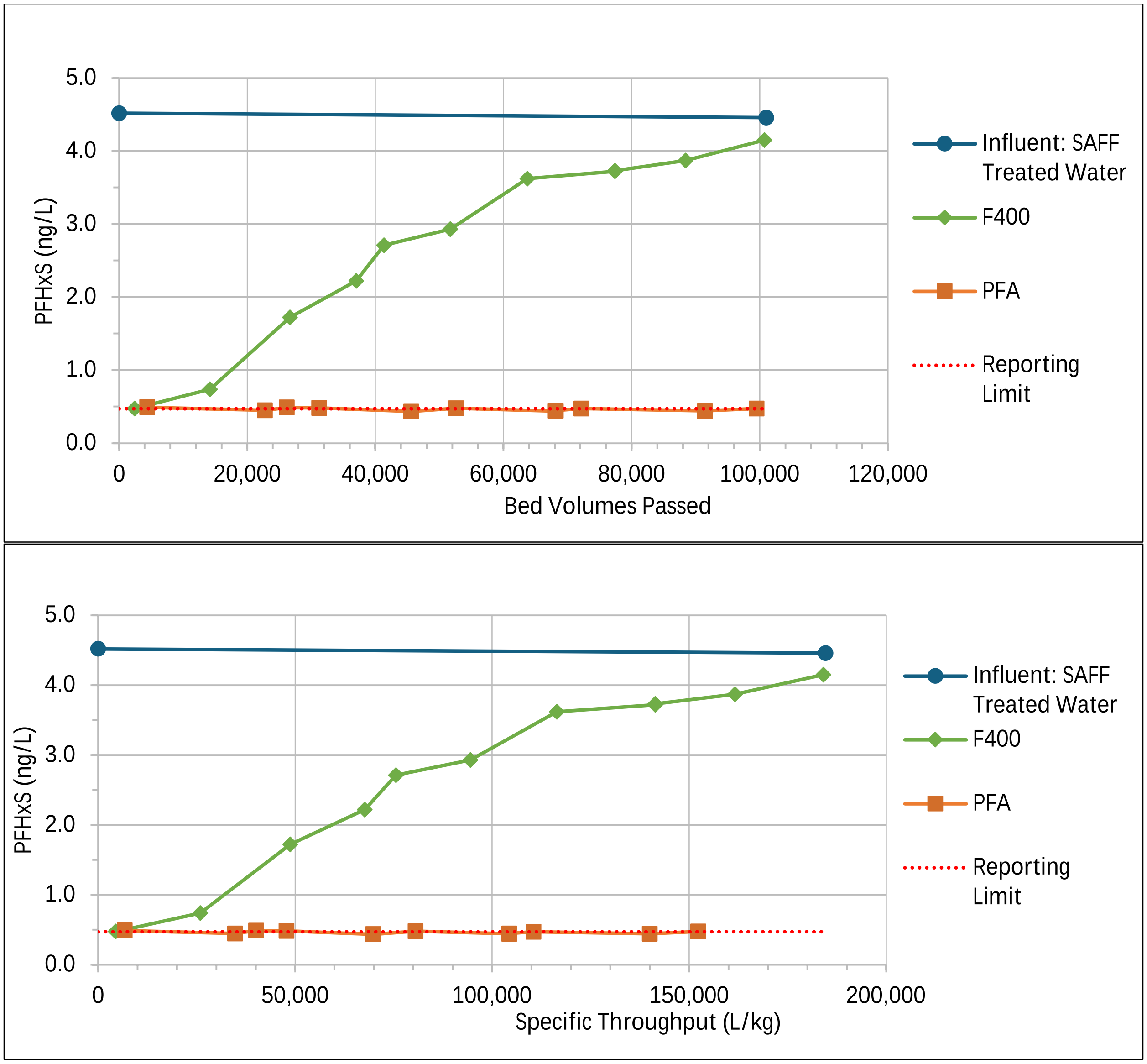


Figure H.102: PFHxS Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

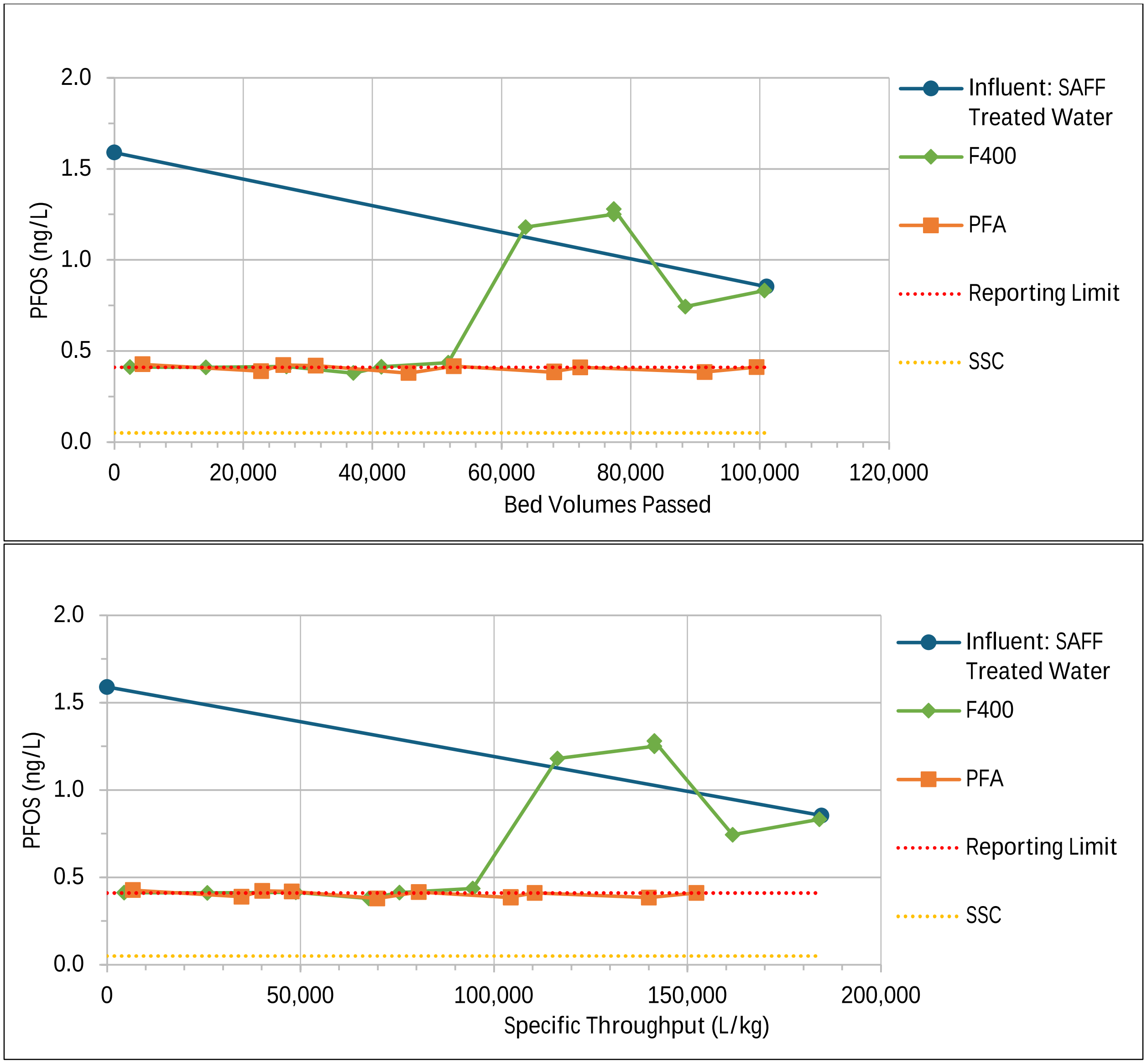


Figure H.103: PFOS Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

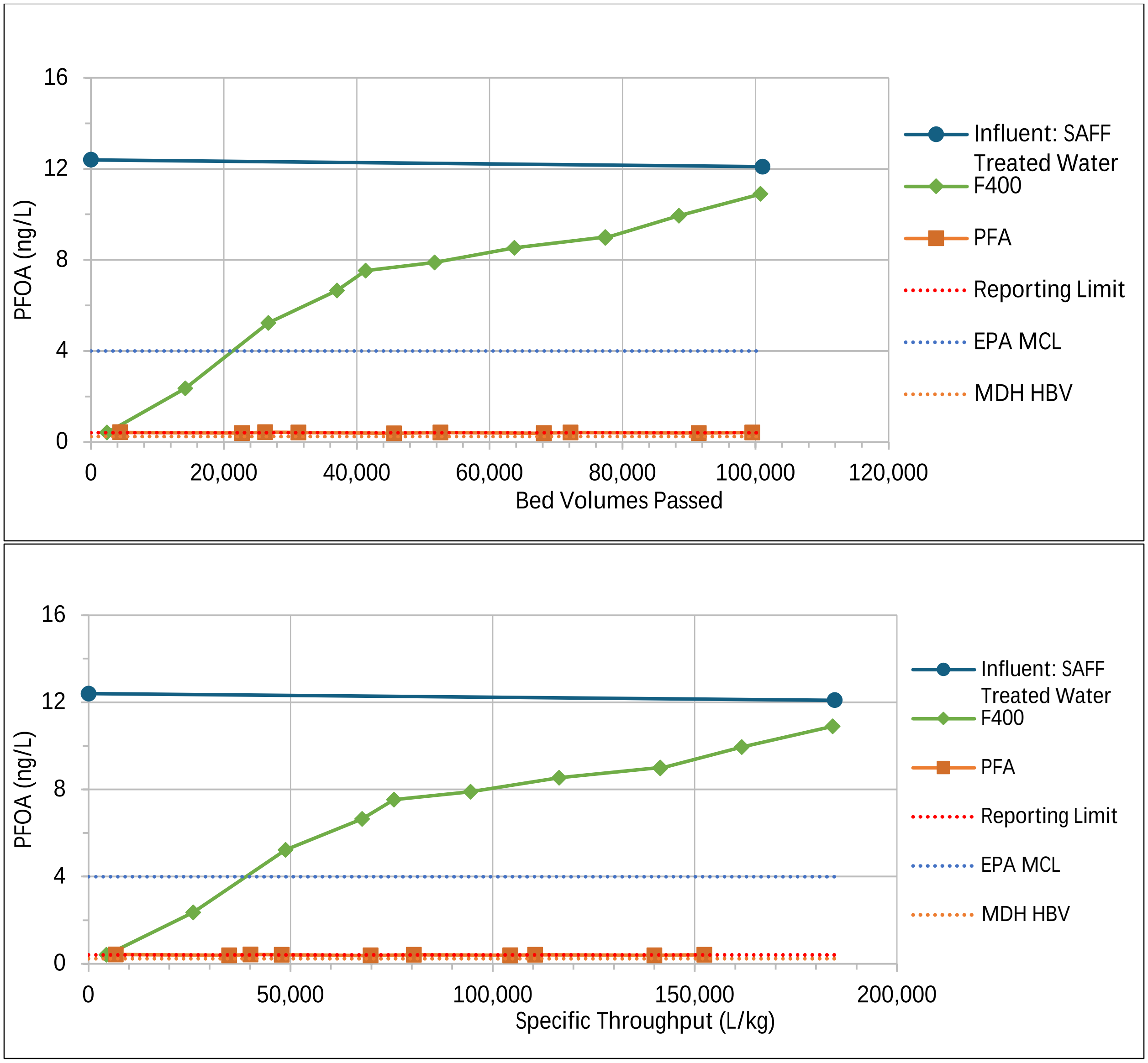


Figure H.104: PFOA Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

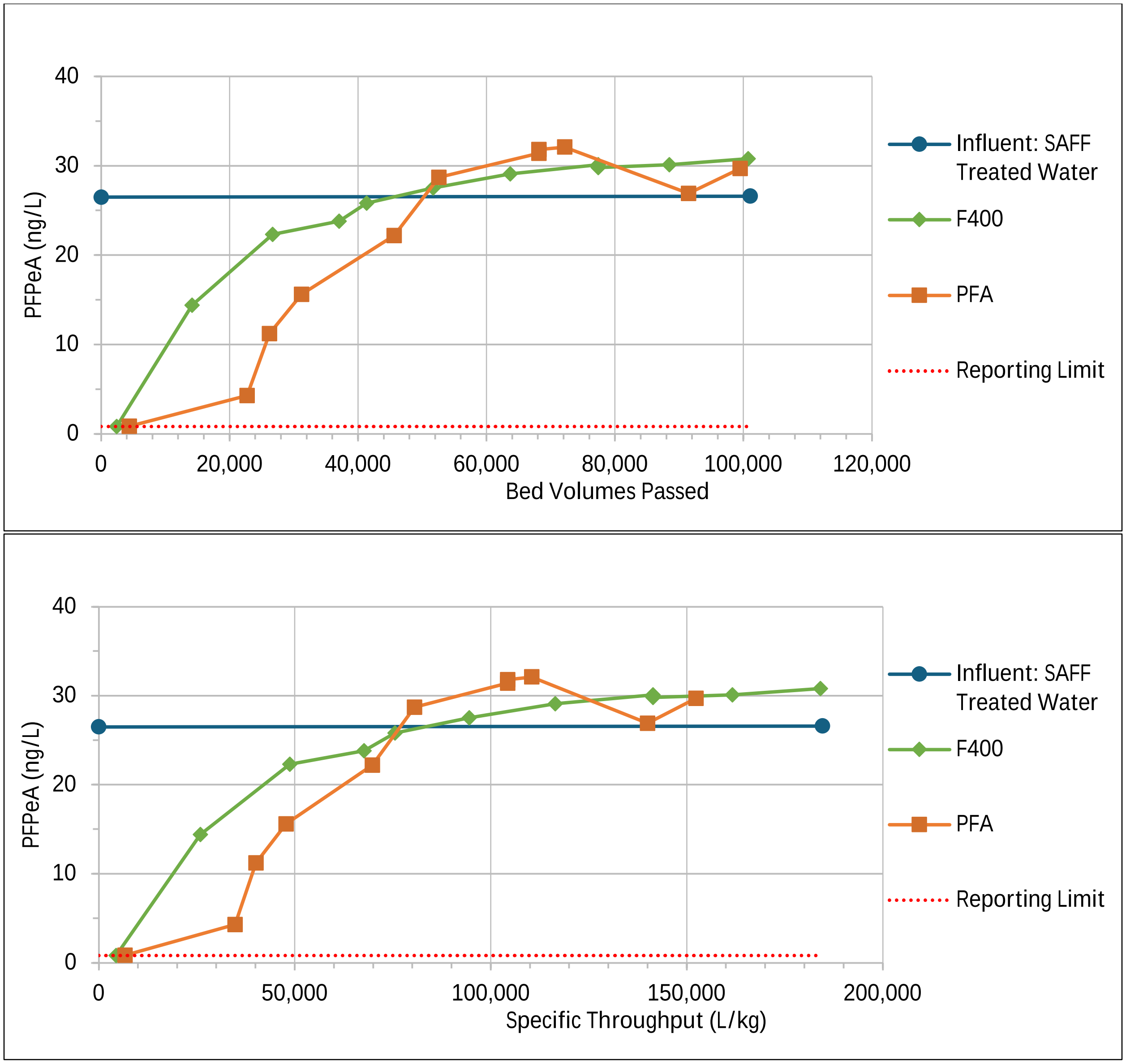


Figure H.105: PFPeA Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

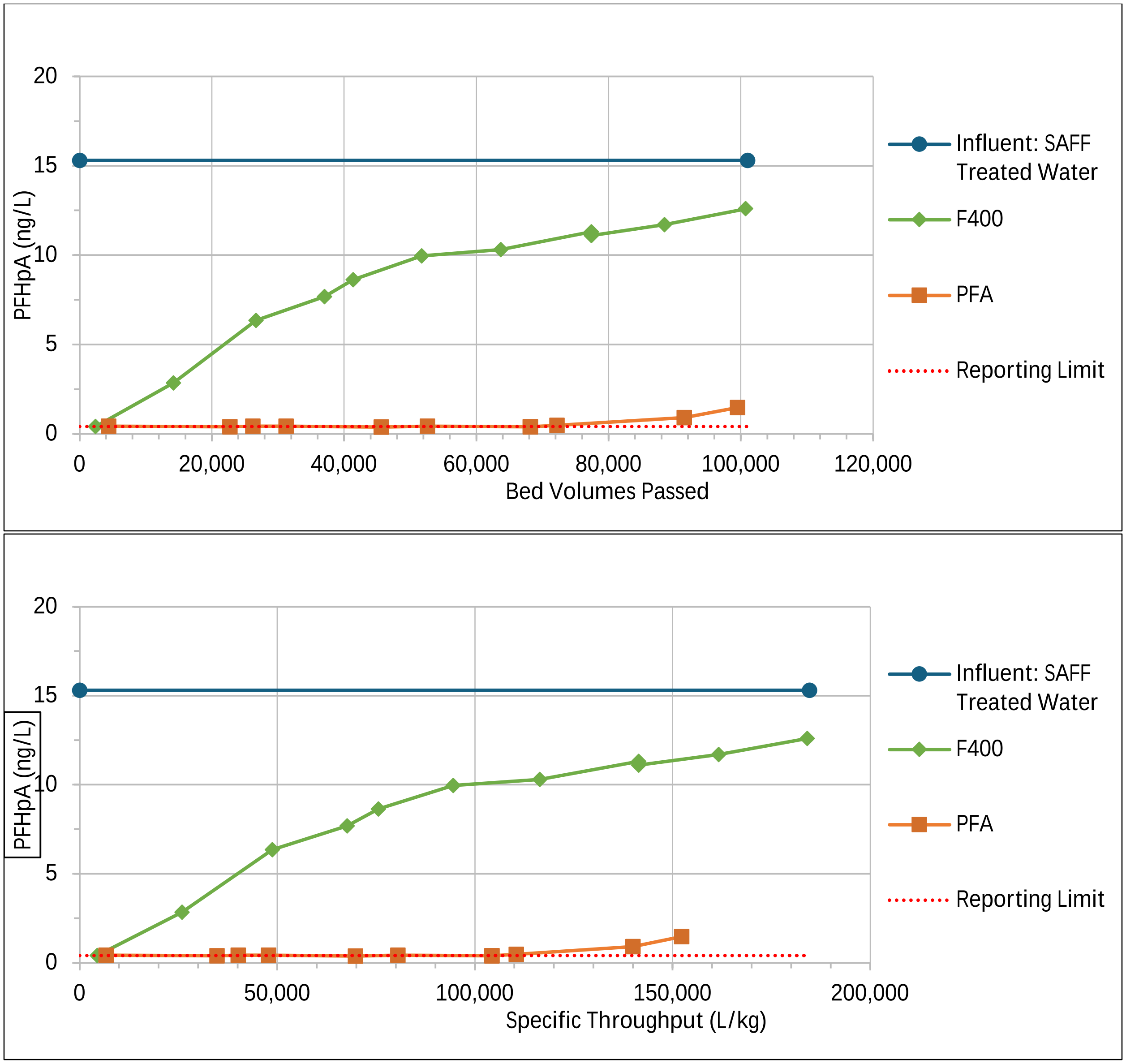


Figure H.106: PFHpA Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

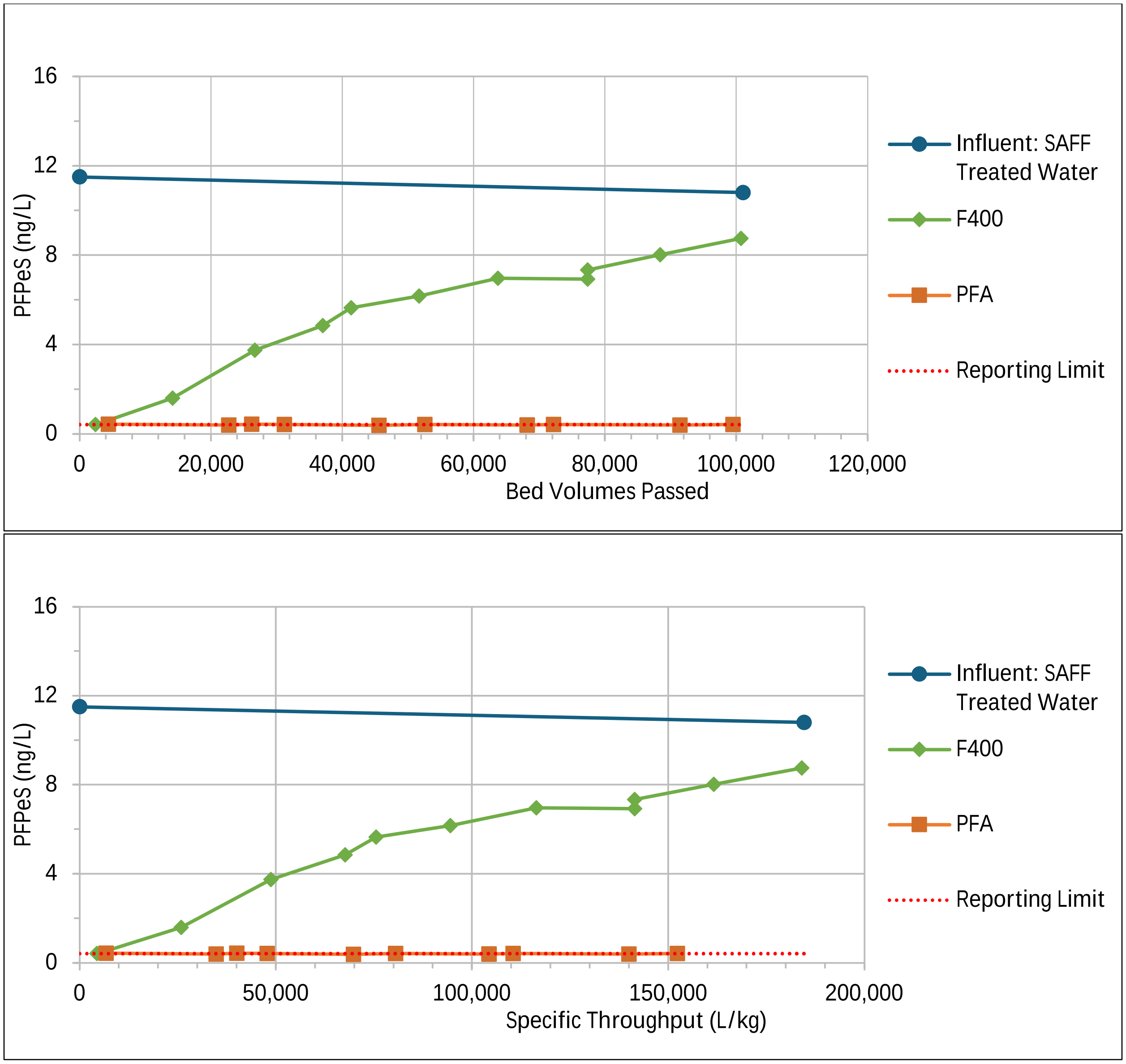
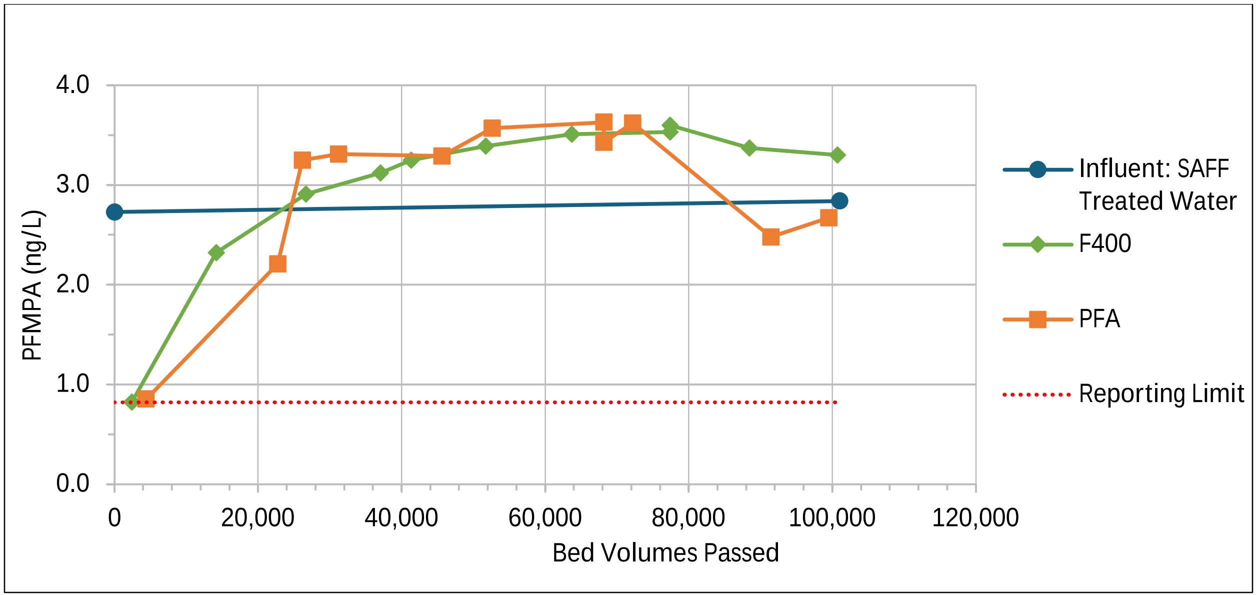


Figure H.107: PFPeS Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.



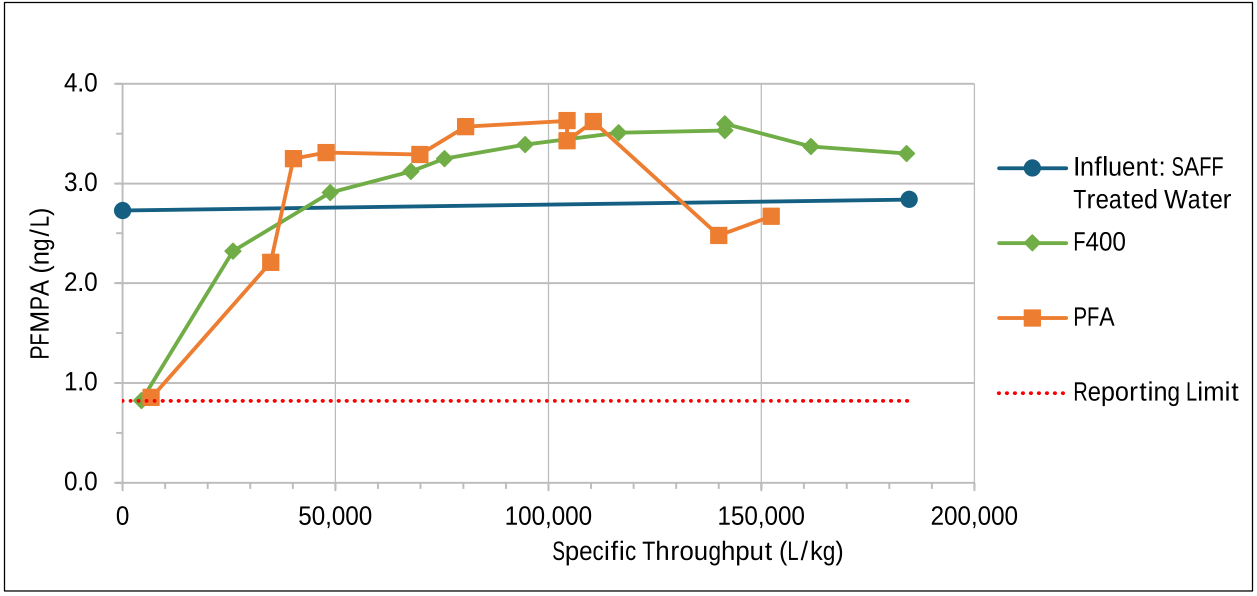


Figure H.108: PFMPA Concentrations vs Bed Volumes & Specific Throughput for SAFF® Treated Waters.

H8 Additional Tables

H8.1 Metals Pretreatment Results

Table H.23: Total Organic Carbon Results from Oxidation Tests.

Treatment	Oxidation (%)	Sample Condition	TOC (mg/L)
H_2O_2	100	Supernatant	<1
H_2O_2	100	Centrifuged	<1
H_2O_2	100	10µm Filtered	1.5
H_2O_2	100	1µm Filtered	<1
NaOCl	50	Supernatant	4.2
NaOCl	50	Centrifuged	2.8
NaOCl	50	10µm Filtered	3.6
NaOCl	50	1µm Filtered	2.4
$KMnO_4$	50	Supernatant	<1
$KMnO_4$	50	Centrifuged	<1
$KMnO_4$	50	10µm Filtered	<1
$KMnO_4$	50	1µm Filtered	<1
NaOCl + Greensand+	73	4 hours	<1
NaOCl + Greensand+	58	8 hours	<1
NaOCl + Greensand+	51	12 hours	<1
NaOCl + Greensand+	44	16 hours	<1
NaOCl + Greensand+	-	BW	2
NaOCl + Greensand+	-	BW-Rinse	1.2
NaOCl + Pyrolusite	73	4 hours	<1
NaOCl + Pyrolusite	58	8 hours	<1
NaOCl + Pyrolusite	51	12 hours	<1
NaOCl + Pyrolusite	44	16 hours	<1
NaOCl + Pyrolusite	-	BW	4.5
NaOCl + Pyrolusite	-	BW-Rinse	4.5

Legend: BW = backwash; DUP = duplicate; KMnO4 = potassium permanganate; mg/L = milligram per liter; NaOCl = sodium hypochlorite; P816E = ChemTreat Inc., anionic polymer; ppm = parts per million; TOC = total organic carbon.

H8.2 Detailed Results for RSSCTs

In the tables presented in this section:

- Bold results indicate detections;
- Blue text with “J” indicates the result is an estimated value; and
- Cells with “<” a value presented indicate the result is less than the reporting limit. The value shown is the reporting limit.

H8.2.1 Jordan Aquifer Groundwater PFAS Results

Table H.24: RSSCT PFAS Results for Jordan Aquifer Influent.

Elapsed Time (d)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFNA (ng/L)	PFDA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFHpS (ng/L)	PFOS (ng/L)	PFOSA (ng/L)	PFMPA (ng/L)	PFMBA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.00	743	25.1	34	13.8	163	0.795 J	0.573 J	9.68	11.2	19.9	3.04	120	<0.399	1.21 J	0.418 J	1146	2.45
0.00	748	24.8	34.5	13.3	163	0.741 J	0.648 J	10.2	11.1	19.9	3.01	122	0.572 J	1.38 J	0.409 J	1154	2.45
4.09	706	23.6	31.7	12.6	150	0.639 J	0.571 J	9.27	10.4	19.2	2.51	102	0.429 J	1.26 J	0.393 J	1071	2.36
8.18	746	25.1	34.4	12.9	161	0.79 J	0.604 J	10.1	11.2	20.1	2.77	119	0.455 J	1.2 J	0.427 J	1146	2.48
8.18	747	24.7	34.5	12.7	163	0.809 J	0.594 J	9.91	10.8	19.9	3.04	115	0.566 J	1.27 J	0.421 J	1144	2.46

Table H.25: RSSCT PFAS Results for Jordan Aquifer F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFNA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFHpS (ng/L)	PFOS (ng/L)	PFOSA (ng/L)	PFMPA (ng/L)	PFMBA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	2,393	4,364	129	1.46 J	1.21 J	<0.42	3.12	<0.42	<0.42	<0.422	<0.482	<0.42	1.05 J	0.828 J	<0.839	<0.42	137	0.26
1.15	14,182	25,870	820	20.20	21.90	6.53	70.30	<0.42	5.66	4.68	7.51	0.773 J	29.00	0.52 J	1.14 J	<0.42	988	1.05
2.15	26,452	48,253	794	24.70	30.00	9.73	110.00	0.475 J	8.22	7.90	12.30	1.33 J	48.90	0.586 J	1.36 J	0.425 J	1050	1.59
2.98	36,608	66,780	790	25.30	32.50	11.00	123.00	0.519 J	8.92	8.79	14.20	1.53 J	54.70	<0.388	0.88 J	0.405 J	1072	1.79
3.33	40,813	74,450	771	26.00	34.30	11.30	133.00	0.432 J	9.28	9.37	15.60	1.70	58.00	0.469 J	<0.836	0.434 J	1071	1.95
4.18	51,088	93,193	779	26.30	35.00	12.20	133.00	0.526 J	9.79	10.20	16.80	1.79	56.80	<0.432	1.26 J	<0.432	1083	2.10
5.18	62,906	114,751	786	27.70	38.00	12.80	148.00	0.53 J	11.00	11.00	17.80	1.84	57.60	0.474 J	<0.874	0.453 J	1113	2.21
6.28	75,912	138,477	764	26.80	37.30	13.70	154.00	0.629 J	10.60	11.50	19.40	2.10	65.30	0.815 J	1.38 J	<0.482	1108	2.42
6.28	75,912	138,477	769	26.80	37.80	13.00	156.00	0.662 J	10.60	11.40	19.90	2.05	64.20	0.884 J	1.42 J	<0.483	1114	2.48
7.17	86,714	158,181	764	26.50	38.20	13.50	160.00	0.523 J	10.50	11.20	18.90	2.14	70.30	0.424 J	1.06 J	0.442 J	1118	2.33
8.15	98,591	179,847	765	26.60	38.00	13.80	161.00	0.699 J	10.70	11.60	19.20	2.05	65.90	<0.512	1.46 J	<0.512	1116	2.41

Table H.26: RSSCT PFAS Results for Jordan Aquifer PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFOA (ng/L)	PFOS (ng/L)	PFMPA (ng/L)	PFMBA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	4,571	6,994	<1.59	<0.795	<0.398	<0.398	<0.398	<0.795	<0.398	0	0.25
1.00	23,296	35,648	227	<0.763	<0.382	<0.382	<0.382	<0.763	<0.382	227	0.24
1.15	26,844	41,077	531	0.939 J	<0.411	<0.411	0.419 J	<0.822	<0.411	532	0.26
1.37	31,919	48,843	621	1.67 J	<0.414	<0.414	<0.414	<0.829	<0.414	623	0.26
2.00	46,343	70,915	763	4.33	<0.381	<0.381	<0.381	0.994 J	<0.381	768	0.24
2.31	53,395	81,706	802	10.00	0.577 J	<0.412	<0.412	1.39 J	<0.412	814	0.26
2.98	68,944	105,499	784	16.20	1.52 J	<0.389	<0.389	1.15 J	<0.389	803	0.24
2.98	68,944	105,499	830	16.50	1.63	<0.392	<0.392	1.53 J	<0.392	850	0.25
3.15	72,953	111,634	827	21.90	2.66	<0.413	<0.413	1.6 J	<0.413	853	0.26
3.98	92,057	140,867	730	26.20	5.71	0.483 J	<0.391	1.06 J	0.449 J	764	0.25
4.33	100,030	153,068	798	31.30	10.20	0.42 J	<0.415	1.14 J	0.526 J	842	0.26

H8.2.2 Shakopee Aquifer Groundwater PFAS Results

Table H.27: RSSCT PFAS Results for Shakopee Aquifer Influent.

Elapsed Time (d)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFNA (ng/L)	PFDA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFHpS (ng/L)	PFOS (ng/L)	PMFPA (ng/L)	TOTAL PFAS (ng/L)	Hazard Index
0.00	435	27.10	43.80	31.40	320.00	2.78	2.95	15	15	33.5	7.56	442	2.84 J	1379	4.17
4.09	427	26.60	42.20	29.70	312.00	2.24	2.83	14.5	15.1	32.2	6.91	390	2.8 J	1304	3.97
8.18	435	26.60	42.60	31.10	342.00	3.26	7.78	15.1	15.3	34.6	12.1	1120	2.75 J	2088	4.35

Table H.28: RSSCT PFAS Results for Shakopee Aquifer F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFNA (ng/L)	PFDA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFHpS (ng/L)	PFOS (ng/L)	PMFPA (ng/L)	TOTAL PFAS (ng/L)	Hazard Index
0.19	2,371	4,323	21.2	<0.849	<0.425	<0.425	<0.425	<0.425	<0.425	<0.425	<0.427	<0.488	<0.425	<0.425	<0.849	22	0.27
1.15	14,151	25,798	401	8.65	4.54	1.5 J	8.54	<0.421	<0.421	1.26 J	<0.423	0.596 J	<0.421	3.53	1.45 J	432	0.28
2.15	26,526	48,358	431	17.80	16.10	8.00	62.20	<0.418	<0.418	5.59	3.29	5.65	0.493 J	33.20	2.17 J	586	0.84
2.98	36,799	67,085	410	20.00	20.90	10.80	91.70	0.514 J	0.436 J	7.35	4.72	8.95	0.889 J	54.30	2.33 J	633	1.20
3.33	41,094	74,916	442	22.40	25.20	13.30	112.00	0.681 J	0.643 J	9.17	5.67	11.40	1.25 J	74.70	2.56 J	721	1.51
4.18	51,640	94,141	440	24.30	29.00	15.50	149.00	0.945 J	0.688 J	10.90	7.37	14.40	1.56 J	86.40	2.49 J	784	1.87
5.18	63,963	116,606	458	26.20	31.90	16.50	151.00	0.955 J	0.825 J	12.20	8.00	16.20	1.68	86.20	2.69 J	813	2.07
6.28	77,628	141,518	446	27.20	33.50	18.40	165.00	1.11 J	0.592 J	12.80	9.09	17.90	1.88 J	91.50	2.86 J	829	2.29
6.28	77,628	141,518	448	26.50	33.70	18.30	167.00	0.864 J	0.651 J	13.20	9.25	17.50	1.88	94.50	3.02 J	834	2.22
7.17	88,574	161,473	451	27.30	35.30	20.40	189.00	1.11 J	0.931 J	13.90	10.20	19.20	2.30	123.00	2.79 J	896	2.42
8.15	100,866	183,882	447	28.40	36.70	22.00	204.00	1.31 J	1.18 J	14.80	10.70	21.80	2.87	142.00	2.15 J	935	2.72

Table H.29: RSSCT PFAS Results for Shakopee Aquifer PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFOS (ng/L)	PFMPA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	4,402	6,819	34.4	<0.847	<0.424	<0.424	0.61	<0.424	<0.847	35	0.27
1.00	22,595	35,004	349	6.47	0.883 J	<0.389	0.47	<0.389	1.71 J	359	0.24
1.15	26,055	40,364	439	13.80	2.27	<0.426	0.474 J	<0.426	2.39 J	458	0.27
1.37	31,083	48,154	457	17.70	3.76	<0.418	0.513 J	<0.418	2.45 J	481	0.26
2.00	45,477	70,453	455	22.30	7.01	0.483 J	0.682 J	0.459 J	2.77 J	489	0.24
2.31	52,506	81,342	442	23.80	12.80	0.996 J	1.24 J	0.61 J	2.75 J	484	0.26
2.98	68,001	105,347	446	26.90	18.50	2.00	3.18	0.575 J	2.68 J	500	0.24
2.98	68,001	105,347	411	26.20	18.40	1.90	3.11	0.685 J	2.55 J	464	0.24
3.15	71,992	111,531	441	26.60	23.60	2.62	4.66	0.568 J	2.8 J	502	0.26
3.98	91,129	141,178	459	29.00	31.00	5.27	9.09	0.549 J	2.9 J	537	0.24
4.33	99,127	153,569	443	28.70	33.40	7.18	13.60	0.487 J	2.67 J	529	0.26

H8.2.3 SAFF® Treated Groundwater PFAS Results

Table H.30: RSSCT PFAS Results for SAFF® Influent.

Elapsed Time (d)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFOS (ng/L)	PFMPA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.00	426	26.5	40.4	15.3	12.4	14.7	11.5	4.52	1.59 J	2.73 J	555.64	0.72
4.09	431	26.6	41.3	15.3	12.1	14.1	10.8	4.46	0.854 J	2.84 J	559.35	0.70

Table H.31: RSSCT PFAS Results for SAFF® F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFOS (ng/L)	PFMPA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	2,420	4,423	47.10	<0.824	<0.412	<0.412	<0.412	<0.412	<0.414	<0.474	<0.412	<0.824	47.10	0.26
1.15	14,187	25,928	431.00	14.40	11.00	2.84	2.36	4.16	1.59 J	0.738 J	<0.41	2.32 J	470.41	0.29
2.15	26,693	48,784	433.00	22.30	22.50	6.35	5.23	8.67	3.74	1.72 J	<0.414	2.91 J	506.42	0.40
2.98	37,037	67,690	428.00	23.80	25.90	7.68	6.65	10.40	4.85	2.22	<0.379	3.12	512.62	0.44
3.33	41,359	75,588	442.00	25.80	29.10	8.63	7.53	11.60	5.64	2.71	<0.413	3.25 J	536.77	0.51
4.18	51,718	94,520	443.00	27.50	31.50	9.96	7.89	13.00	6.16	2.93	<0.435	3.39 J	545.33	0.55
5.18	63,711	116,440	452.00	29.10	34.30	10.30	8.53	14.40	6.96	3.62	1.18 J	3.51	563.90	0.62
6.28	77,389	141,438	446.00	30.10	35.30	11.30	9.00	15.10	6.92	3.72	1.25 J	3.53 J	562.22	0.65
6.28	77,389	141,438	445.00	29.80	35.00	11.10	8.97	15.00	7.33	3.73	1.28 J	3.6 J	560.81	0.65
7.17	88,451	161,655	444.00	30.10	37.80	11.70	9.94	15.50	8.02	3.87	0.743 J	3.37	566.10	0.64
8.15	100,729	184,093	443.00	30.80	37.20	12.60	10.90	17.10	8.75	4.15	0.832 J	3.3 J	569.09	0.68

Table H.32: RSSCT PFAS Results for SAFF® PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFMPA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	4,398	6,733	12.20	<0.854	<0.427	<0.427	<0.854	12.20	0.27
1.00	22,733	34,804	382.00	4.28	<0.389	<0.389	2.21 J	388.49	0.24
1.15	26,196	40,105	447.00	11.20	0.751 J	<0.423	3.25 J	462.20	0.27
1.37	31,215	47,788	455.00	15.60	1.29 J	<0.419	3.31 J	475.20	0.26
2.00	45,609	69,826	430.00	22.20	2.82	<0.379	3.29	458.31	0.24
2.31	52,604	80,534	459.00	28.70	6.66	<0.416	3.57	497.93	0.26
2.98	68,156	104,345	456.00	31.40	11.90	<0.383	3.63	503.34	0.24
2.98	68,156	104,345	456.00	31.80	12.30	<0.387	3.43	503.94	0.24
3.15	72,179	110,504	454.00	32.10	15.90	0.468 J	3.62	506.09	0.26
3.98	91,448	140,003	395.00	26.90	20.20	0.907 J	2.48 J	445.88	0.24
4.33	99,504	152,337	428.00	29.70	26.60	1.47 J	2.67 J	489.03	0.26

H8.2.4 Washington County Landfill PFAS Results

Table H.33: RSSCT PFAS Results for WCL Influent.

Elapsed Time (d)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFOS (ng/L)	PFMPA (ng/L)	PFMBA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.00	394,000	2,640	3,730	665	13,700	243 J	149 J	243 J	330 J	258 J	198 J	416,156	77.62
4.00	398,000	2,630	3,640	665	13,800	259 J	152 J	243 J	308 J	238 J	193 J	420,128	77.93
8.18	399,000	2,650	3,630	721	14,700	245 J	159 J	273 J	768	232 J	196 J	422,574	81.26

Table H.34: RSSCT PFAS Results for WCL F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFBS (ng/L)	PFPeS (ng/L)	PFHxS (ng/L)	PFOS (ng/L)	PFMPA (ng/L)	PFMBA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	2,418	4,391	245,000	448 J	220 J	<104	244 J	<104	<105	<120	<104	<208	<104	245,912	65.49
1.26	14,819	26,915	404,000	2,930	3,230	538	9,480	292 J	122 J	185 J	155 J	255 J	210 J	421,397	72.60
2.15	26,142	47,478	402,000	2,920	3,590	637	12,500	283 J	158 J	245 J	260 J	259 J	201 J	423,053	79.46
2.98	36,450	66,199	378,000	2,750	3,350	632	12,600	296 J	115 J	242 J	256 J	226 J	198 J	398,665	76.54
3.33	40,752	74,013	399,000	2,860	3,620	693	12,800	305 J	152 J	265 J	267 J	248 J	215 J	420,425	80.60
4.18	51,309	93,186	403,000	2,830	3,780	664	13,200	303 J	152 J	285 J	267 J	247 J	203 J	424,931	83.72
5.18	63,657	115,613	411,000	2,970	3,850	696	13,900	325 J	167 J	276 J	254 J	255 J	215 J	433,908	82.33
6.28	77,317	140,421	405,000	2,850	3,700	723	13,500	308 J	148 J	286 J	212 J	229 J	212 J	427,168	83.43
6.28	77,317	140,421	398,000	2,850	3,790	705	13,300	314 J	139 J	257 J	241 J	252 J	206 J	420,054	80.21
7.17	88,267	160,308	404,000	2,910	3,720	698	13,900	310 J	172 J	285 J	264 J	256 J	210 J	426,725	80.58
8.15	100,540	182,599	405,000	2,920	3,720	670	13,300	331 J	133 J	271 J	251 J	241 J	222 J	427,059	81.58

Table H.35: RSSCT PFAS Results for WCL PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	PFBA (ng/L)	PFPeA (ng/L)	PFHxA (ng/L)	PFHpA (ng/L)	PFOA (ng/L)	PFMPA (ng/L)	PFMBA (ng/L)	Total PFAS (ng/L)	Hazard Index
0.19	4,415	6,723	69,700	54	7.85 J	<3.13	<3.13	22.7 J	3.18 J	69,788	1.96
1.00	22,932	34,920	395,000	1,700	630	<104	160 J	231 J	117 J	397,838	65.17
1.15	26,466	40,302	446,000	2,950	1,520	<103	422	297 J	215 J	451,404	64.77
1.37	31,536	48,022	438,000	3,170	2,040	112 J	631	272 J	241 J	444,466	65.17
2.00	45,976	70,009	410,000	3,160	2,820	203 J	1,310	261 J	234 J	417,988	65.17
2.31	53,062	80,799	420,000	3,160	3,680	338 J	2,320	268 J	231 J	429,997	65.49
2.98	68,645	104,529	400,000	3,030	3,950	453	3,640	244 J	231 J	411,548	64.77
2.98	68,645	104,529	409,000	3,100	4,160	467	3,700	252 J	225 J	420,904	64.77
3.15	72,663	110,648	423,000	3,160	4,320	542	4,830	274 J	228 J	436,354	62.22
3.98	91,861	139,881	405,000	2,930	4,120	625	6,370	257 J	217 J	419,519	65.17
4.33	99,867	152,072	409,000	2,760	4,290	691	7,600	254 J	205 J	424,800	62.83

H8.2.5 Jordan Aquifer Groundwater Results

Table H.36: TOC and Probe Measurement Results for Jordan Aquifer Influent.

Elapsed Time (d)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.00	1.9	7.9	363.1	352.5	0.33
0.00	-	7.87	358.4	331.5	0.37
4.09	2	8.11	431.8	334.4	0.39
4.09	1.9	-	-	-	-
8.18	2	-	-	-	-

Table H.37: TOC and Probe Measurement Results for Jordan Aquifer F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	2,695	4,916	<1.00	-	-	-	-
1.00	12,311	22,457	-	7.99	424.2	351.6	0.29
1.18	14,486	26,424	1.10	-	-	-	-
1.98	24,323	44,370	-	7.99	437.9	324.2	0.4
2.18	26,753	48,803	1.40	-	-	-	-
2.98	36,608	66,780	1.60	8.17	397.8	350.4	0.45
3.15	38,638	70,483	-	8.08	391.7	348.7	0.55
3.18	38,937	71,029	1.50	-	-	-	-
4.18	51,088	93,193	1.50	-	-	-	-
5.18	62,906	114,751	1.60	-	-	-	-
6.33	76,446	139,450	1.60	-	-	-	-
6.33	76,446	139,450	1.60	-	-	-	-
6.98	84,475	154,096	-	8.23	416.8	342.2	0.63
7.19	87,018	158,736	1.60	-	-	-	-
7.98	96,831	176,637	-	8.2	440.8	348.2	0.75
8.18	98,807	180,241	1.70	-	-	-	-

Table H.38: TOC and Probe Measurement Results for Jordan Aquifer PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	5,144	7,872	1.30	-	-	-	-
1.00	23,296	35,648	1.50	7.46	422.1	432.5	0.26
1.18	27,425	41,967	1.50	-	-	-	-
1.39	32,480	49,701	1.50	-	-	-	-
2.00	46,343	70,915	1.60	7.44	433.1	587.3	0.59
2.15	49,859	76,296	-	7.94	403.9	352.4	0.23
2.33	53,975	82,593	1.60	-	-	-	-
2.98	68,944	105,499	1.70	8.1	452	351.1	0.53
2.98	68,944	105,499	1.70	-	-	-	-
3.18	73,514	112,492	1.60	-	-	-	-
3.42	79,035	120,941	-	8.03	426.8	328.8	0.34
3.98	92,057	140,867	1.70	8.13	411.9	338.8	0.45
4.18	96,518	147,693	1.60	-	-	-	-

H8.2.6 Shakopee Aquifer Groundwater Results

Table H.39: TOC and Probe Measurement Results for Shakopee Aquifer Influent.

Elapsed Time (d)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.00	<1.00	7.97	427.6	824.8	0.3
4.09	<1.00	8.08	442	815.7	0.59
8.18	<1.00	-	-	-	-

Table H.40: TOC and Probe Measurement Results for Shakopee Aquifer F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	2,669	4,866	<1.00	-	-	-	-
1.00	12,281	22,388	-	8.11	482.4	856.4	0.09
1.18	14,456	26,353	<1.00	-	-	-	-
1.98	24,381	44,447	-	8.15	458.2	827.9	0.12
2.18	26,826	48,905	<1.00	-	-	-	-
2.98	36,799	67,085	<1.00	8.25	436.4	848.1	0.1
3.15	38,897	70,911	-	8.11	440.9	843.3	0.09
3.18	39,201	71,464	<1.00	-	-	-	-
4.18	51,640	94,141	<1.00	-	-	-	-
5.18	63,963	116,606	<1.00	-	-	-	-
6.33	78,165	142,497	<1.00	-	-	-	-
6.33	78,165	142,497	<1.00	-	-	-	-
6.98	86,311	157,347	-	8.41	434.1	1021	0.23
7.19	88,879	162,028	<1.00	-	-	-	-
7.98	98,715	179,960	-	8.53	434.4	824.7	0.08
8.18	101,169	184,435	<1.00	-	-	-	-

Table H.41: TOC and Probe Measurement Results for Shakopee Aquifer PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	4,947	7,663	<1.00	-	-	-	-
1.00	22,595	35,004	<1.00	7.46	452.3	1011	0.24
1.18	26,624	41,246	<1.00	-	-	-	-
1.39	31,642	49,020	<1.00	-	-	-	-
2.00	45,477	70,453	<1.00	7.33	449.7	1289	0.29
2.15	48,968	75,862	-	7.99	432.6	787.8	0.3
2.33	53,084	82,239	<1.00	-	-	-	-
2.98	68,001	105,347	<1.00	8.12	450.3	1284	0.32
2.98	68,001	105,347	<1.00	-	-	-	-
3.18	72,550	112,395	<1.00	-	-	-	-
3.42	78,069	120,946	-	8.08	429.8	797.4	0.27
3.98	91,129	141,178	<1.00	8.23	420.6	836.2	0.22
4.18	95,611	148,122	<1.00	-	-	-	-

H8.2.7 SAFF® Treated Groundwater Results

Table H.42: TOC and Probe Measurement Results for SAFF® Influent.

Elapsed Time (d)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.00	<1.00	8.3	450.1	815.8	0.35
8.18	1.6	8.27	450.8	801	0.37
8.18	1	8.34	436.2	810.5	0.36

Table H.43: TOC and Probe Measurement Results for SAFF® F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	2,720	4,971	<1.00	-	-	-	-
1.00	12,274	22,433	-	8.32	480.2	823.4	0.12
1.18	14,497	26,495	<1.00	-	-	-	-
1.98	24,530	44,831	-	8.36	448.7	812.7	0.12
2.18	26,996	49,338	<1.00	-	-	-	-
2.98	37,037	67,690	<1.00	8.37	426.7	852	0.11
3.15	39,152	71,556	-	8.38	441.8	810.8	0.1
3.18	39,458	72,114	<1.00	-	-	-	-
4.18	51,718	94,520	<1.00	-	-	-	-
5.18	63,711	116,440	<1.00	-	-	-	-
6.33	77,926	142,419	<1.00	-	-	-	-
6.33	77,926	142,419	<1.00	-	-	-	-
6.98	86,158	157,464	-	8.42	430.5	822.5	0.12
7.19	88,756	162,213	<1.00	-	-	-	-
7.98	98,582	180,171	-	8.48	444.1	811.9	0.14
8.18	101,031	184,645	1.20	-	-	-	-

Table H.44: TOC and Probe Measurement Results for SAFF® PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	4,949	7,576	<1.00	-	-	-	-
1.00	22,733	34,804	<1.00	7.45	441.4	1110	0.23
1.18	26,766	40,977	<1.00	-	-	-	-
1.39	31,773	48,644	<1.00	-	-	-	-
2.00	45,609	69,826	<1.00	7.43	457.5	1198	0.22
2.15	49,081	75,141	-	8.33	433.1	811.2	0.1
2.33	53,180	81,417	<1.00	-	-	-	-
2.98	68,156	104,345	<1.00	8.38	421.7	839.8	0.11
2.98	68,156	104,345	<1.00	-	-	-	-
3.18	72,743	111,367	<1.00	-	-	-	-
3.42	78,293	119,864	-	8.37	463.4	819	0.11
3.98	91,448	140,003	<1.00	8.4	429.2	840.5	0.1
4.18	95,961	146,913	<1.00	-	-	-	-

H8.2.8 Washington County Landfill Results

Table H.45: TOC and Probe Measurement Results for WCL Influent.

Elapsed Time (d)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.00	5.4	7.85	354	1133	0.53
4.00	5.4	7.83	355.6	1168	0.35
8.18	5.2	-	-	-	-

Table H.46: TOC and Probe Measurement Results for WCL F400 Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	2,721	4,941	2.50	-	-	-	-
0.92	10,845	19,697	-	7.82	367.4	1084	0.36
1.29	15,162	27,536	4.60	-	-	-	-
1.98	23,947	43,493	-	7.87	348.9	1060	0.31
2.18	26,446	48,030	5.00	-	-	-	-
2.98	36,450	66,199	5.00	7.47	388.3	1120	0.35
3.15	38,551	70,016	-	7.78	409.3	1044	0.23
3.18	38,855	70,568	4.90	-	-	-	-
4.18	51,309	93,186	5.00	-	-	-	-
5.18	63,657	115,613	5.00	-	-	-	-
6.33	77,855	141,399	5.00	-	-	-	-
6.33	77,855	141,399	4.90	-	-	-	-
6.98	86,006	156,202	-	7.77	414.9	1054	0.55
7.19	88,573	160,864	5.00	-	-	-	-
7.98	98,396	178,705	-	7.91	414.3	1017	0.46
8.18	100,843	183,148	5.00	-	-	-	-

Table H.47: TOC and Probe Measurement Results for WCL PFA Effluents.

Elapsed Time (d)	Bed Volumes (BV)	Specific Throughput (L/kg)	TOC (mg/L)	pH	ORP (mV)	EC (uS/cm)	Turbidity (NTU)
0.22	4,970	7,569	3.50	-	-	-	-
1.00	22,932	34,920	4.50	7.36	441.7	1723	0.6
1.18	27,045	41,183	4.70	-	-	-	-
1.39	32,098	48,877	4.80	-	-	-	-
2.00	45,976	70,009	5.00	7.9	359.8	1147	0.35
2.15	49,509	75,390	-	7.65	336.2	1163	0.41
2.33	53,643	81,685	5.00	-	-	-	-
2.98	68,645	104,529	5.20	7.86	353.9	1102	0.37
2.98	68,645	104,529	5.20	-	-	-	-
3.18	73,226	111,504	5.10	-	-	-	-
3.42	78,764	119,939	-	7.59	389.5	1042	0.42
3.98	91,861	139,881	5.10	7.75	389.9	816.4	0.22
4.18	96,340	146,702	5.10	-	-	-	-